JET PROPULSION LABORATORY
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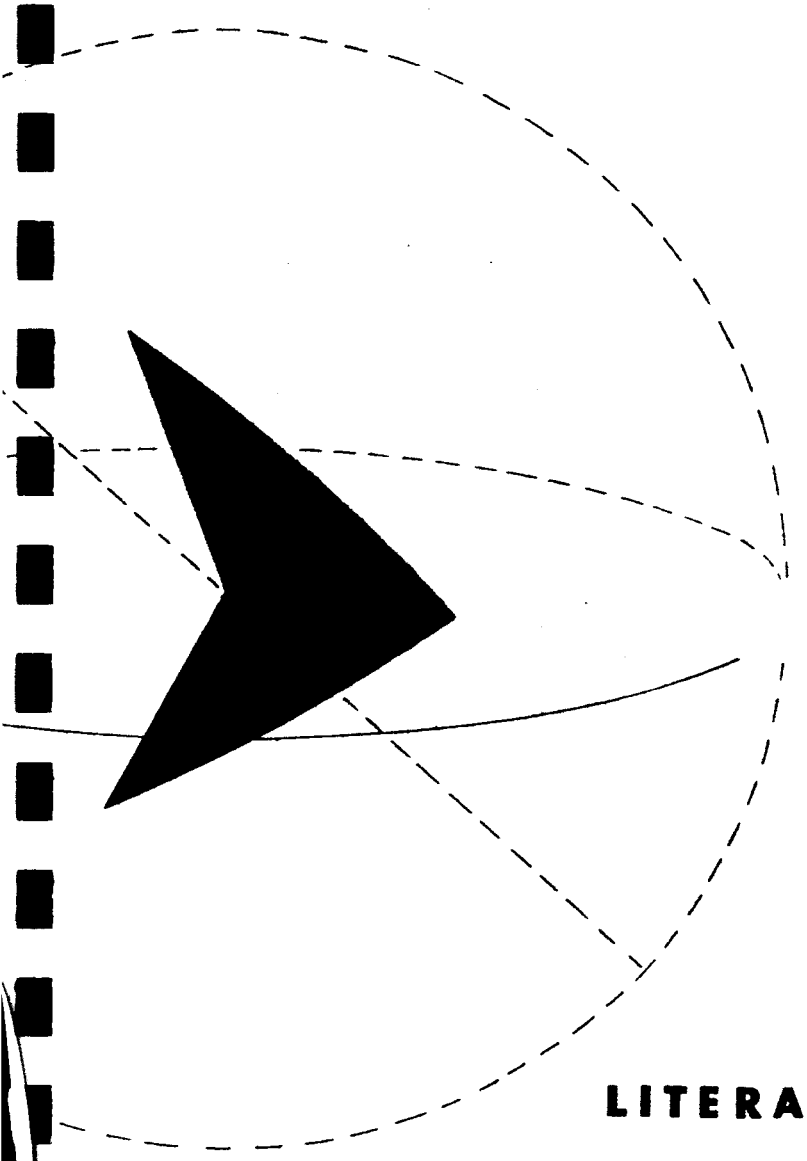

LITERATURE SEARCH NO. 308

ELECTRETS

FEBRUARY 1961

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA, CALIFORNIA

37 pp

FOREWORD

The phenomenon of a permanent or long-lasting charge occurring in some dielectrics after application of an electric field has been known for many years. In 1892, Oliver Heaviside proposed the name "electret" for such a dielectric. The most commonly known electret materials are waxes, polymers, and ceramics, although some substances such as sodium chloride and sulphur have also been found to exhibit electret properties. Electret properties are believed to be dependent on the occurrence of one, or the interaction of both, of the following effects: (1) a heterocharge, which is essentially a dielectric absorption (due to ion migration, dipole orientation, or Maxwell's microscopical heterogeneities) frozen-in throughout the volume of the specimen; and (2) a homocharge, which consists of a persistent ionic surface charge deposited by electrical breakdown of the interface between the electrode and the dielectric.

During recent years a special interest has been shown in the theory, properties, and possible uses of electrets. At the request of personnel of the Jet Propulsion Laboratory (JPL), a compilation has been made of recent references on the subject, together with a sampling of earlier reports. The literature search is published for distribution to other interested organizations working in the field of astronautics.

The material is divided into two sections:

Electrets. This section includes theory, properties, production, and uses of electrets. Reports (including patents) are arranged alphabetically by originating source, and open literature (including periodical literature, books, and conferences) is arranged chronologically.

Associated Subjects. Topics such as general polarization theory, dielectric behavior of the pertinent materials, and variation of properties with an electrostatic field are only sampled.

The following sources were consulted: *Chemical Abstracts, (CA)*, 1946–1958; *Physics Abstracts (PA)*, 1946–November 1960; *Engineering Index (EI)*, 1955–1959; *Electrical Engineering Abstracts (EEA)* 1946–1959; Armed Services Technical Information Agency, Technical Abstract Bulletins (ASTIA), through December 1960; JPL Translation and Subject Files; *Journal of the Franklin Institute*, 1960; *Reviews of Modern Physics*, January–July 1960; *Journal of Physics and Chemistry of Solids*, 1960; *Journal of Polymer Science*, January–August 1960; *Physical Review*, January–November, 1960; *Journal of Applied Physics*, 1960; *Applied Science and Technology Index (AS&T)*, 1958–January 1961; *Soviet Physics–Solid State*, 1960; *Soviet Physics–JETP*, 1959–1960; *Technical Translations (TT)*, January–September, 1960 and December 13, 1960; *Modern Plastics*, March–August 1960; *Review of Scientific Instruments*, 1959 and 1960 (except June and December); *Journal of Physical Chemistry*, 1959 and March–July 1960; *Journal of Chemical Physics*, 1959–1960; *The American Ceramic Society Bulletin*, 1959 and January 1961; *Journal of the American Ceramic Society*, 1959–January 1961; *Ceramic Abstracts*, 1959–January 1961; and miscellaneous periodicals.

Abstracts found in the reference sources are presented, and an author index is provided.

The compiler wishes to acknowledge the assistance of Robert J. Gardner and Dr. Robert F. Landel of the Jet Propulsion Laboratory in the arrangement of material.

ELECTRETS

Reports

1. AN ELECTRET HYDROPHONE
Cook, E. O.
December 8–10, 1952
Defence Research Board, Canada (In cooperation with the Naval Research Establishment)
Fourth Symposium, Physics 5
AD-11,239

A type of hydrophone is described which uses electrostatic induction derived from the permanent electrostatic field of an electret. The moving element is a circular metal plate which is clamped around its periphery to one end of a cylindrical brass case. The plate diameter is 7.6 cm, and the thickness is 0.030 in. One face of the electret (9-cm diam. by 0.6-cm thick) carries a thin metal disk to which a massive plate is attached by an insulating cement. The opposite face is placed within a few mils of the clamped diaphragm. Experiments showed a 0.005-cm amplitude of vibration of the disk at 155 c. Discussions are included of the linear relationship between the output voltage and disk amplitude, the frequency response and sensitivity, and the properties and manufacture of electrets. (ASTIA)

2. RADIACMETER–ELECTRET TYPES
Marvin, H. B.
December 1, 1953
General Electric Co., Syracuse, N. Y.
Final Engineering Report, NObsr-49,200
AD-35,301

A development was undertaken to design and produce a small quantity of electrets to meet field service conditions for use as personal dosimeters for measuring the time integral of intensity of ionizing radiations. Samples were built and tests made under simulated service conditions. Accuracy of 10 percent was needed under wide ranges of service conditions and of the radiation characteristics. After a survey at midpoint of the contract, it was decided to terminate the development. Operative samples of the radiacmeters were delivered. (ASTIA)

3. RESEARCH STUDIES ON ELECTRETS
Wiseman, G. G., Feaster, G., Moon, R., et al.
February 1–May 15, 1951
Kansas, University of, Lawrence
Quarterly Progress Report 1, DA 36-039-sc-5467
TIP U 18,495

The investigation was made to conduct studies directed toward the development of electrets, thereby learning their fundamental nature and investigating the feasibility of their use in electrical devices. Apparatus was purchased, designed and built to test various electret substances and to record their behavior as a function of time under various conditions of humidity, temperature, etc.

4. RESEARCH STUDIES ON ELECTRETS
Wiseman, G. G., Feaster, G. R., Wild, J., et al.
May 15–August 15, 1951
Kansas, University of, Lawrence
Quarterly Progress Report 2, DA 36-039-sc-5467
TIP U 19,444

An automatically recording instrument to measure electret charges has been built around a Brown electronic strip-chart recorder. This instrument has continuously recorded the effects of gamma rays and humidity upon both electrets and ordinary frictional charges. A crude electret microphone and a crude dosimeter for gamma rays have been made to operate.

5. RESEARCH STUDIES ON ELECTRETS
Baumann, N. P., Feaster, G. R., Moon, R., et al.
August 15–November 15, 1951
Kansas, University of, Lawrence
Quarterly Progress Report 3, DA 36-039-sc-5467
TIP U 20,423

Measurements of an electret's charge during the manufacturing process has been made for absorptive and nonabsorptive dielectrics with widely divergent results. Measurements were made to detect a hysteresis effect in carnauba wax. No hysteresis was apparent in fields up to 18 kv/cm. Analysis was made of the input circuit of the electret charge-recording apparatus. Charge patterns on electrets and nonelectrets were photographed by first exposing the charged surface to charged dust.

6. RESEARCH STUDIES ON ELECTRETS
Baumann, N. P., Brown, H. P., et al.
November 15, 1951–February 15, 1952
Kansas, University of, Lawrence
Quarterly Progress Report 4, DA 36-039-sc-5467
TIP U 21,338

7. RESEARCH STUDIES ON ELECTRETS
Baumann, N. P., Brown, H., Feaster, G. R., et al.
February 15–May 15, 1952
Kansas, University of, Lawrence
Quarterly Progress Report 5, DA 36-039-sc-5467
ATI-157900

A vacuum and pressure system has been built to measure electret charges over a wide range of pressure. Tests have been run on a number of biphenyl compounds, and some of them produce electrets. Dielectric constant and loss factor measurements have been completed on three electret materials (Gelva V-7, plexiglas, and carnauba wax) and on one nonelectret (paraffin). The results have been used in understanding the nature of a heterocharge. Some dc absorption measurements have also been made. Preliminary studies of an electret earphone, and electromagnetic radiation from a sparking electret are reported.

8. RESEARCH STUDIES ON ELECTRETS
Baumann, N. P., Feaster, G. R., Prosser, F. W., et al.
May 15–August 15, 1952
Kansas, University of, Lawrence
Quarterly Progress Report 6, DA 36-039-sc-5467
ATI-165918

Electrets have been manufactured at room temperatures, permitting prefabrication with respect to geometry and surface finish. Electrically-strong plexiglas electrets have been manufactured. Experiments with five wax mixtures show the dependence of room-temperature relaxation times on composition. Decay pulses have been investigated in carnauba wax and in Gelva V-7. The effect of temperature-altered relaxation time on the decay of an unshorted electret has been investigated. The effects of scraping, humidity, and pressure on surface charge are reported. Results are compared with theory.

9. RESEARCH STUDIES ON ELECTRETS
Feaster, G. R., Fisher, J. S., Levi, M. W., et al.
August 15–November 15, 1952
Kansas, University of, Lawrence
Quarterly Progress Report 7, DA 36-039-sc-5467
TIP U 25,468

10. RESEARCH STUDIES ON ELECTRETS
Feaster, G. R., Fisher, J. S., et al.
November 15, 1952–February 15, 1953
Kansas, University of, Lawrence
Quarterly Progress Report 8, DA 36-039-sc-5467
AD-6,421

The fundamental nature of electrets is being studied as well as the feasibility of their application in electrical devices. Electrets manufactured and measured in a vacuum showed a larger heterocharge and a smaller homocharge than those prepared and measured at atmospheric pressure. Strong electrets with half-lives of four to eight hours were prepared from barium titanate. Equations were derived which showed that an electret with a large dielectric constant can hold a large surface charge without the occurrence of an interfacial breakdown at atmospheric pressure. The molding charge appearing on polyvinyl acetate after the stripping of aluminum foil showed no definite dependence upon stripping temperature, cooling rate, or molten time. An analysis revealed that the optimum sensitivity of an electret microphone should occur with equal electrical thicknesses of the air gap and the electret. (ASTIA)

11. RESEARCH STUDIES ON ELECTRETS
Wiseman, G. G.
February 15–June 15, 1953
Kansas, University of, Lawrence
Quarterly Progress Report 9, DA 36-039-sc-5467
AD-17,317

Tests showed polyethylene to be an excellent nonabsorptive dielectric in which other materials could be embedded for study. At −20°C and below, the reversal of a carnauba-wax electret was completely arrested. At −10°C a barely perceptible change in charge occurred, while at room temperature it reversed in the normal fashion. The heterocharge characteristics of electret substances were expressed in terms of a quantity called the intrinsic polarization function. The dissectible capacitor technique developed for electret measurements was applied to the measurement of this function. An electret of Gelva V-7 built and measured in a vacuum of 10^{-5} mm of Hg attained an apparent surface charge density of 10^{-8} coulomb/cm^2. Anomalous interfacial leakage currents were observed in these experiments. The minimum energy required to cause pyrolysis of lead azide was measured for point-to-plane and ball-to-plane electrode configurations. Decomposition was initiated with a spark energy of about 10^{-3} joule with a 3-mm-radius ball. (ASTIA)

12. RESEARCH STUDIES ON ELECTRETS
Wiseman, G. G., Alexander, W. R., et al.
June 1–August 31, 1953
Kansas, University of, Lawrence
Quarterly Progress Report 10, DA 36-039-sc-5467
AD-18,720

An application of the two-charge theory of electret formation provided a simple method of preparing lucite electrets with larger and more stable homocharges. Calculations showed that dielectric inhomogeneities of two basic types (where the dielectric constant and conductivity change throughout the medium, and where the dielectric consists of a sandwich of plane-parallel slabs) give rise to dielectric polarizability. Formulas were derived which express the behavior of electrets during manufacture and storage in terms of measurable properties such as resistivity and intrinsic polarization. A homocharge was formed on Gelva V-7 electrets in a vacuum of about 10^{-5} mm of Hg when strong manufacturing fields were used. Tests showed that a properly made electret has a sufficiently long life for practical applications, even in those devices where perfect short-circuiting is not feasible. (ASTIA)

13. RESEARCH STUDIES ON ELECTRETS
Wiseman, G. G., Alexander, W. R., et al.
September 1–November 31, 1953
Kansas, University of, Lawrence
Quarterly Progress Report 11, DA 36-039-sc-5467
AD-25,835

Apparatus was assembled for measuring the complex dielectric constants of solid mixtures over the 0.5- to 20-kc range. Considerable difficulty was encountered in diluting the solid dielectric with a known amount of polar substance. Generated triboelectric charges introduced considerable error in dissectible capacitor measurements of slow polarization unless suitable precaution was taken. Attempts to form ice electrets were unsuccessful; the resistivity of the ice samples was too low. Electrets of pure sulfur, polyethylene-sulfur mixtures, and mixtures of polyethylenes of widely different molecular weights were studied. Charges of the mixtures decayed rapidly to zero. The mixtures of unlike polyethylenes do not exhibit the type of volume polarization necessary for the formation of electrets. The complex dielectric constants of solid, nonpolar dielectrics diluted with polar compounds are being measured over a range of temperatures. The dissectible capacitor method was used to measure the intrinsic polarization function of carnauba wax at one temperature. The data agreed with a t^n relationship at long times but not at short times. A barium titanate electret reversed to the homocharge state in less than one second after the polarizing field was removed. The electret forming time appeared to be similarly rapid. Studies of the electrical noise pulses generated in decaying electrets were expanded to include electrets formed below the melting point. The practical difficulties encountered in making an electret microphone of high voltage output, wide frequency response, and long life were largely overcome. (ASTIA)

14. RESEARCH STUDIES ON ELECTRETS
Wiseman, G. G., Alexander, W. R., et al.
December 1, 1953–February 28, 1954
Kansas, University of, Lawrence
Quarterly Progress Report 12, DA 36-039-sc-5467
AD-28,251

Measurements of the complex dielectric constant of a nonpolar solid, paraffin, diluted with a small quantity of polar material, ethanol, were made at low frequencies over a range of temperatures. A plot of the values of the loss maxima vs. the logarithm of the frequency at which maximum loss occurs gives a straight line. The first of a series of measurements of the intrinsic polarization function for carnauba wax and lucite were completed. The experiments showed that lucite could possess a greater volume polarization than carnauba wax and that it has a longer relaxation time. Experiments at elevated temperatures showed that the slowly absorbed volume polarization was linear in electric field up to 3.3 kv/cm. Surface charge measurements of a ceramic $BaTiO_3$ sample both during field application and afterward did not show clear-cut evidence of a persistent volume polarization. A large fraction of the applied field exists across the air gap below the measuring electrode because of the sample's high dielectric constant. Discharge across this gap deposits large surface charges on the sample which obscure the volume polarization effects. Electrical noise pulses were measured in ceramic $BaTiO_3$ samples after the temporary application of a polarizing field. The dependence of the rate and duration of the pulses upon the polarizing voltage, temperature, and period of application of the polarizing voltage was measured. A review of the electret experiments and a survey of the literature was made which shows the importance of homocharge-generating processes other than discharge across the gap between the electrode and dielectric. (ASTIA)

15. RESEARCH STUDIES ON ELECTRETS
Wiseman, G. G., Byers, D. H., et al.
March 1–May 31, 1954
Kansas, University of, Lawrence
Quarterly Progress Report 13, DA 36-039-sc-5467
AD-37,327

An analytical expression was obtained for the intrinsic polarization function of carnauba wax at 40°C. The behavior of an electret, with and without homocharge, was predicted by using this expression as a basis; experimental and predicted values were in agreement. Test results indicated that an EtOH–paraffin mixture exhibits ordinary dielectric loss at audio frequencies near room temperature; this loss, however, goes over to the long-time, persistent polarization characteristic of electrets when the mixture is cooled by liquid N. $BaTiO_3$ continued to show very strong and peculiar effects as an electret; some of these effects were explained by assuming that electrical discharges occur across the dielectric-electrode interface. Measurements of $BaTiO_3$ and carnauba wax electrets, with and without evaporated metal surfaces, indicated that the pulses from polarized $BaTiO_3$ originate from discharges across the dielectric-electrode gap; pulses from polarized carnauba wax, however, originated in the volume of the dielectric. Heterocharge polarization of polyethylene was observed in vacuum when strong fields were applied. (ASTIA)

16. RESEARCH STUDIES ON ELECTRETS

Wiseman, G. G.
February 15, 1951–August 31, 1954
Kansas, University of, Lawrence
Quarterly Report 14 (Final), DA 36-039-sc-5467
AD-50,935

Improved methods for preparing and measuring electrets under controlled conditions were developed, and conditions for accurate measurements were formulated. A study of the electret properties of 17 pure substances, 22 plastics, and 19 mixtures revealed no reliable correlation between the chemical nature of the substances and their electret properties. Crystalline alignment, as revealed by X-ray diffraction, is neither a necessary nor a sufficient condition for a substance to possess electret-forming properties. A two-charge theory was formulated in mathematical terms which explains electret behavior in terms of dielectric properties and which takes into account the homocharge–heterocharge interaction through the static field equations for the electret-electrode system. A number of experiments were performed to test implications of the theory and to furnish data for the practical application of electrets. These included observations of the effects of temperature, ionizing radiation, surface-layer removal, humidity, pressure variations, and the removal of the short-circuiting electrodes. The following electret devices were constructed: radiation dosimeters, microphones, a spark initiator for explosives, an earphone, a spark-signal transmitter, and an electrometer. (ASTIA)

17. RESEARCH AND DEVELOPMENT STUDIES OF ELECTRETS

Wiseman, G. G., Beeler, J. R., Merts, A. L.
September 1–November 30, 1954
Kansas, University of, Lawrence
Quarterly Progress Report 1, DA 36-039-sc-63111
AD-54,792

An attempt was made to clarify the relationship that exists between the electret effect and the chemical nature of the substances used. Some anomalous effects were obtained with $BaTiO_3$ electrets. Experiments were conducted to obtain a normal electret reversal at higher polarizing voltages. The reversal to the homocharge polarity was rapid and the resulting homocharge decayed too rapidly with time. Pressurization applied to nylon was an unsuccessful means of preventing interfacial discharge during the measurements of electret charge formation. High vacuum retarded the charge transfer. Measurements on plexiglas at 64°C showed that part of the volume polarization was not reversible; this indicated some combination with the surface charge. Vapors, like water, affected the electrets in several ways. Water absorbed in the volume of the electret had a profound effect. (ASTIA)

18. RESEARCH AND DEVELOPMENT STUDIES OF ELECTRETS

Wiseman, G. G., Beeler, J. R.
December 1, 1954–February 28, 1955
Kansas, University of, Lawrence
Quarterly Progress Report 2, DA 36-039-sc-63111
AD-74,439

Investigation of Electret Substances: Anomalous results with $BaTiO_3$ during both polarization and decay have been traced to leakage in the dielectric-electrode interface. Calculations show that the effect of dust particles and other causes of surface leakage are greatly magnified with $BaTiO_3$ because of its high dielectric constant. When proper precautions were taken $BaTiO_3$ was caused to exhibit typical electret behavior at very low polarizing voltages, 46 v in this instance.

Study of Electret Characteristics: A study of the effects of polar and nonpolar vapors on the volume and surface charges of electrets was made. Both polar and nonpolar dielectrics were investigated. Several effects were found to occur with the presence of vapor: changes in surface

resistivity, changes in volume resistivity, and changes in volume polarizability. This last effect, not previously observed for electrets, is probably the most pronounced one and tests have shown that the general increase in polarizability with absorbed vapor is in a large part due to the plasticizing effect of the vapor.

Practical Applications: The electret in an electret microphone has decayed faster than a "twin" electret stored under supposedly similar conditions. The cause of this decay is not known. (ASTIA)

19. RESEARCH AND DEVELOPMENT STUDIES OF ELECTRETS

Wiseman, G. G.
March 1–May 31, 1955
Kansas, University of, Lawrence
Quarterly Progress Report 3, DA 36-039-sc-63111
AD-74,438

Investigation of Electret Substances: Rosin, contrary to early reports in the literature, has been found to acquire both homocharges and heterocharges, the molding charge playing a decisive role in determining polarity in many cases. By proper thermal and electrical treatment typical electret reversals were obtained with rosin. These results are consistent with the two-charge, macroscopic theory of electrets.

Study of Electret Characteristics: Tests of two kinds were performed which show that the slow component of volume polarization in plexiglas which is responsible for the electret's heterocharge is drastically affected by its moisture content. Data are given which show the increase of polarization with moisture content. Previous work showed that a similar effect in other polymerized materials arises from the plasticization effect of the water.

Practical Applications: The electret microphone was rebuilt with a different preamplifier circuit and a new electret. The decay of the electret in an electret microphone is shown to be a consequence of the air gap existing between the diaphragm and the electret. (ASTIA)

20. RESEARCH AND DEVELOPMENT STUDIES OF ELECTRETS

Wiseman, G. G., Friauf, R. J., et al.
June 1–August 31, 1955
Kansas, University of, Lawrence
Quarterly Progress Report 4, DA 36-039-sc-63111
AD-79,205

Electret Substances: Extensive dielectric-constant and dielectric-loss-factor measurements were made on crystalline samples of NaCl, AgCl, and S. Charging and discharging currents in NaCl were measured by dc methods. No samples showed evidence of orientational polarization, and electrets formed from them must be polarized by the migration of charge carriers to form a space charge. Evidence of slow charge migration was obtained by observing the charge and discharge currents of an NaCl-filled capacitor by dc methods. Electrets were usually formed from S.

Electret Characteristics: From the two-charge macroscopic theory of electrets, the implication is obtained that an electret will form which will spontaneously undergo two reversals in the sign of its charge. Electrets were formed from carnauba wax and Saran. Each electret underwent two spontaneous alterations in the sign of its charge while being stored between short-circuited electrodes. A more definite effect was observed with S. S electrets were formed by using ultraviolet light.

Practical Applications: A reciprocating type of electret generator was constructed which appears suitable as a substitute for the chemical battery in some high-voltage, low-current applications. The model will deliver about 0.15 μa at 5 kv or about 0.6 μa at 1 kv; the typical operation is 0.5 μa at 2 kv. The generator permits the electret to be well short-circuited while not in use. (ASTIA)

21. RESEARCH AND DEVELOPMENT STUDIES OF ELECTRETS

Wiseman, G. G., Coffman, J. W.
September 1, 1954–November 30, 1955
Kansas, University of, Lawrence
Final Report, DA 36-039-sc-63111
AD-93,215

Studies were made of substances known to have little or no orientational polarization, and electret properties were observed in some of them. The effects of water vapor and other vapors on the behavior of a variety of materials during electrical polarization and depolarization were observed. Although the presence of the vapor facilitates charge transfer across the dielectric-electrode interface, the major effect on electret behavior is caused by vapor absorption into the volume of the dielectric with resultant plasticization. Electrets were made which utilize the superficial ionization produced by α particles and the more penetrating effects produced by ultraviolet light. The effects of penetrating X-radiation on the polarization and depolarization of electrets were investigated for several dielectric substances; the effects

are primarily attributed to ionization and photoemission in the dielectric-electrode interface. Efforts were directed toward improving the electret electrometer and microphone. A 0.5 μa, 2-kv electret generator was designed, built, and tested. The output of the electret generator compares favorably with those of two devices which were considered as substitutes for chemical batteries: the miniature electrostatic source and the nuclear battery. (ASTIA)

22. ELECTRETS
Rohrbaugh, J. H.
June 1–August 31, 1952
New York University, Washington Square College, New York
Quarterly Report 1, AF 19(604)407
ATI-172615

A standardized method of preparing carnauba-wax electrets to give fairly uniform electret strengths has been devised. To attain quantitative results, it has been found necessary to avoid applying the field while the electret material is molten. A new method of charge measurement which permits measuring the charge of the electret without unshielding it at any time has been tried. Measurements on charge recovery are being carried out. The method of discharging with iron filings shows unexpected characteristics. The discharge currents of electrets under various conditions are being measured. Discharge current vs. time curves measured to date are straight lines on loglog paper. The slope depends upon the discharge conditions.

23. ELECTRETS
Rohrbaugh, J. H.
September 1–November 30, 1952
New York University, Washington Square College, New York
Quarterly Report 2, AF 19(604)407
AD-4,544

An expression obtained for the growth of the homocharge agreed well with experimental data for carnauba-wax electrets made at different forming voltages. Initial-charge variations which were attributed to disturbances of the surface charge in removing the wax sample from the mold had no apparent effect on the rate-of-charge change for electrets formed at reasonably high voltages (10 kv/cm). An electret formed in a 7400-v/cm field for four days at room temperature had a high initial current discharge which fell rapidly to that of an electret formed at low voltage with heat-treatment. Iron filings placed on the faces of an electret resulted in a discharge current–time relationship similar to that of an electret removed from the forming field and discharged between plane electrodes. The influence of the long-chain molecules in carnauba wax and charge migration are discussed as possible causes of the greater dipole polarization than predicted by the Debye–Langerin expression. (ASTIA)

24. ELECTRETS
Rohrbaugh, J. H.
December 1, 1952–February 28, 1953
New York University, Washington Square College, New York
Quarterly Report 3, AF 19(604)407
AD-9,521

25. ELECTRETS
Rohrbaugh, J. H.
March 1–May 31, 1953
New York University, Washington Square College, New York
Quarterly Report 4, AF 19(604)407
AD-17,442

Experiments were performed with carnauba-wax electrets having thicknesses of 2, 4, and 8 mm. Field strengths varying from 5 to 25 kv/cm were used. The electrets were removed from the forming field and stored at constant temperature; their discharge currents as a function of time were plotted. The total discharge from a thick electret was markedly greater than that from a thin electret made at the same field strength. A high dc field affected the dielectric constant of the carnauba wax at temperatures close to the melting point and at frequencies below about 500 cps. The dielectric constant was also affected by aging the wax at 69°C. Rough measurements were made of the thermal lags involved in heating and cooling electrets. The thermal relaxation time of an electret 4 mm thick was about three minutes. Experiments on two-layer electrets showed that a high applied field can cause the migration of charge in the wax to form a heterocharge under certain conditions. This supports the view that heterocharge is a space-charge polarization rather than a dipole polarization. (ASTIA)

26. ELECTRETS
Rohrbaugh, J. H.
June 1–September 30, 1953
New York University, Washington Square College, New York
Final Report, AF 19(604)407
AD-23,521

Carnauba-wax slabs were prepared by casting and machining them to size, and were then electrified by a separate process at a temperature just below the softening point of the wax. The electrets were made in thicknesses of 2, 4, and 8 mm at field strengths ranging from 5 to 25 kv/cm. After the forming field was turned off, a discharge current was observed from the electrets which after about one hour varied inversely as a nearly linear function of time. The use of a higher forming field strength always produced a correspondingly higher discharge. The maximum surface discharge developed by any of the electrets was 6×10^{-9} coulomb/cm^2. A large discharge which persisted for several minutes was obtained from wax which was electrified and discharged while not completely solidified. The discharge from wax electrified at room temperature, at a low field strength (5 kv/cm), was dependent on the thickness of the wax. Dielectric constant measurements showed two frequency ranges in which new types of polarization were developing. A type of polarization attributed to dipole orientation had a relaxation time of about 1 msec at 27°C. Another type of polarization which was affected considerably by an applied dc field occurred at temperatures close to the softening point of the wax. A new explanation of the electret is presented which is based on the theory of semiconductors. (ASTIA)

27. IMPROVEMENTS IN OR RELATING TO ELECTROMETERS

Gemant, A.
October 2, 1935
U. S. Dept. of Commerce, Washington, D. C.
British Patent 435,950

Electrets are used to furnish the necessary electrostatic field.

28. IMPROVEMENTS IN OR RELATING TO ELECTROSTATIC DEVICES FOR THE INTERCONVERSION OF ELECTRICAL VIBRATIONS AND COMPRESSIONAL VIBRATIONS IN A FLUID MEDIUM

Gemant, A.
November 21, 1935
U. S. Dept. of Commerce, Washington, D. C.
British Patent 438,672

A use of electrets in microphones is presented.

29. PIEZOELECTRIC TRANSDUCERS

Cherry, W. L., Jr.
January 16, 1951
U. S. Dept. of Commerce, Washington, D. C.
U. S. Patent 2,538,554 (Issued to Zenith Radio Corp.)

Permanent piezoelectric effects are produced in solid polycrystalline aggregates (such as Ba titanate or Ba Sr titanate bonded with suitable glass-forming oxides) individually possessing piezoelectric properties below a predetermined transition temperature, by maintaining the aggregate at a temperature below the transition temperature, producing a unidirectional electrostatic polarizing field in the aggregate, and maintaining the polarizing field for a substantial time at least approaching that required for saturation of that effect. (*CA*, 1956, #3968d)

30. RESIN-IMPREGNATED GAS-FILTERING MATERIAL

Green, H. L., Thomas, D. J., Harris, W. J.
November 6, 1951
U. S. Dept. of Commerce, Washington, D. C.
U. S. Patent 2,573,964 (Issued to Minister of Supply, His Majesty's Government of the United Kingdom of Great Britain and Northern Ireland)

A filter material is prepared by combining with animal fibers up to 40 wt percent of a finely divided resin, then electrifying the resin particles and felting the mixture. The resin maintains its charge for a long period if the specific volume resistivity is greater than 10^{17} ohm cm and if the specific surface resistivity is greater than 10^{16} ohms. Resins used are rosin-modified *tert*-butyl-phenol-formaldehyde resin (Beckacite 1643), Congo copal resin, and polystyrene. (*CA*, 1956, #2860h)

Open Literature

31. ELECTRIFICATION OF DIELECTRIC SUBSTANCES

Mikola, S.
***Matematikai es Termeszettudomanyi Ertesito*, v. 30, pp. 30–37, 1923**

When a condenser is charged, ions of great velocity are shot on the surface of the dielectric, forming there double electrical layers and making a complete condenser of the plain dielectric plate. The electrical charge is retained for various lengths of time according to the dielectric. The following insulating materials prepared by Mikola retained the electrical charge obtained in the condenser for weeks and months: mixture of paraffin and wax, paraffin and rosin, paraffin and carbon black, and paper treated with rosin or paraffin. (*CA*, 1926, #2447)

32. ON THE PERMANENT ELECTRET

Eguchi, M.

***Philosophical Magazine, The*, v. 49, pp. 178–192, 1925**

Eguchi stated that in order to maintain the charge on carnauba wax or mixtures for long periods the surface must be short-circuited with metal-foil wrapping or some similar device.

33. ON ELECTRETS

Adams, E. P.

***Franklin Institute, Journal of the*, v. 204, pp. 469–486, 1927**

Evidence has been given that the so-called permanent electrets of Eguchi are not permanent, but that their polarization decays with the time. At room temperatures this decay is too slow to be observed directly; but it is the decay of the polarization that accounts, at least in part, for the presence of the free charges that are always observed. At higher temperatures the results that have been obtained are consistent with the view that the rate of decay of the polarization increases very rapidly with the temperature; so much so that the polarization may be almost completely destroyed at a temperature which is not high enough to cause any appreciable softening of the waxes that form the substance of the electrets.

As is to be expected from Lord Kelvin's hypothesis of the cause of pyroelectricity, these electrets have been shown to possess the pyroelectric property.

The piezoelectric effect, which always accompanies the pyroelectric property, has been shown to be exhibited by these electrets.

34. AN X-RAY STUDY OF ELECTRETS

Ewing, M.

***Physical Review, The*, v. 36, p. 378, 1930**

35. SPACE CHARGE MEASUREMENTS DURING SOLIDIFICATION AND IN THE SOLID STATE

Jaeger, P.

***Annalen der Physik*, v. 21, p. 481, 1934**

36. ELECTRETS

Gemant, A.

***Philosophical Magazine, The*, v. 20, pp. 929–952, November 1935**

Various waxes, and compositions made by dissolving certain materials in waxes, can be permanently electrified, as shown by Eguchi, by application of an electric force of the order of 5 to 10 kv/cm during the process of cooling from a molten state. There are two possible kinds of charges: the heterocharge, which has the opposite sign to the adjacent polarizing electrode, is probably caused by ionic space charges, and is of short duration; and the more permanent homocharge, which is of the same sign as the adjacent polarizing electrode, and is due to dipole molecules. The dipoles are oriented by the polarizing field, and the contraction due to cooling produces a polarization as in piezoelectric materials. Acidic materials, yielding ions, produce a heterocharge, whereas nondissociating dipoles, chiefly esters, lead to the steady homocharge. Electrets are the electrical analogs of permanent magnets, and retain their charge if they are kept dry, with their free surfaces short-circuited. Electrometers and electrostatic microphones are possible applications. (*PA*, 1935, #5191)

37. DIELECTRIC AFTER-EFFECT IN SOLIDIFIED DIELECTRICS

Thiessen, P. A., Winkel, A., Herrmann, K.

***Physikalische Zeitschrift vereinigt mit dem Jahrbuch der Radioaktivität und Electronik*, v. 37, pp. 511–520, July 15, 1936**

Resin-wax mixtures acquire permanent charges if high-voltage stresses are applied during the process of cooling from the molten state. The influence of field strength and electrode materials on these permanent charges is investigated. There are two kinds of charges: (1) with voltage stresses less than 10 kv/cm a charge is produced which is due to movements of the ions in the material to the electrodes; (2) with stresses greater than 10 kv/cm charges of opposite sign are produced due to movements of charge-carriers from the electrodes. Depending on the value of the stress applied during cooling, the permanent charges may therefore be of either sign. (*PA*, 1936, #4339)

38. PERMANENT POLARIZATION OF THE ELECTRET

Groetzinger, G., Kretsch, H.

***Zeitschrift für Physik*, v. 103, no. 5–6, pp. 337–349, 1936**

The permanent polarization which is set up in beeswax if it is cooled in an electric field, is destroyed upon melting. This can be shown by connecting an electrometer to two electrodes touching opposite surfaces of the "electret." Upon melting, the electrometer registers a certain amount of charge. If instead of heating the wax to its melting point it is kept at intermediate temperature, a smaller charge is found. If, however, instead of

solidifying in an external field, the wax is only cooled in a field from a temperature T below the melting point, the polarization can be completely destroyed by heating it again to the temperature T. Applying a h.f. field not only heats the substance but also accelerates the depolarization. It cannot, however, set free more charge than would be set free, at the same temperature, without the h.f. field. (*PA*, 1937, #371)

39. THERMAL CONDUCTIVITY OF ELECTRETS

Groetzinger, G.
***Physikalische Zeitschrift vereinigt mit dem Jahrbuch der Radioaktivität und Electronik*, v. 37, no. 16, pp. 589–592, August 15, 1936**

It is shown experimentally that the electret exhibits a greater thermal conductivity than the unpolarized substance. This alteration in thermal conduction is therefore a criterion for electrets and remains in existence when the electret produces no electrical field. The conductivity experiments were carried out by Schleiermacher's method and full details are included. The results appear to support the hypothesis that in a solid body whose molecules possess a permanent electrical moment, there is a state in which the moment takes up a definite direction without the action of a permanent external field. (*PA*, 1936, #4767)

40. LIBERATION OF ELECTRICAL ENERGY DURING THE FUSION OF ELECTRETS

Frei, H., Groetzinger, G.
***Physikalische Zeitschrift vereinigt mit dem Jahrbuch der Radioaktivität und Electronik*, v. 37, pp. 720–724, October 15, 1936**

It is shown that during the fusion of an electret—made from beeswax—which no longer produces an electric field, a current flows between two electrodes introduced into it. If the substance from which the electret has been prepared had been polarized in the solid state, then the current was essentially weaker. The total quantity of electricity obtained during the fusion is independent of the time which has passed between the production (polarization) and fusion (depolarization). If paraffin, a nonpolar substance, is exposed to an electrical field during solidification or in the solid state, then in both cases, for equal times of exposure, equal amounts of electricity are afforded during the fusion. The experiments indicate that the assumption of an electrical polarization in the electret which is independent of the time is fulfilled when this polarization produces no electrical field. Since the amount of electricity during the fusion is proportional to the field strength up to 13000 v/cm, a linear relationship is indicated between the permanent polarization in the electret and the field strength. (*PA*, 1936, #5670)

41. AN IMPROVED WAY OF MAKING ELECTRETS AND FACTORS WHICH AFFECT THEIR BEHAVIOR

Good, W. M., Stranathan, J. D.
***Physical Review, The*, v. 56, pp. 810–813, 1939.**

42. PIEZOELECTRIC EFFECTS IN ELECTRETS

Williams, P.
1939
South Dakota State College, Brookings
Thesis

43. USE OF ELECTRETS IN ELECTRICAL INSTRUMENTS

Gemant, A.
***Review of Scientific Instruments, The*, v. 11, pp. 65–71, February 1940**

An electret is a permanently electrically polarized material and exhibits an electric field near its free surface which keeps undiminished for years. It is possible to utilize this field in electrical appliances. Experiments and devices on this line are described. (*PA*, 1940, #1272)

44. EFFECT OF PRESSURE ON THE SURFACE CHARGE OF AN ELECTRET

Sheppard, G. E., Stranathan, J. D.
***Physical Review, The*, v. 60, pp. 360–361, 1941**

It is shown that pressures below atmospheric reduce the maximum attainable charge density. Strong electrets stored at pressures higher than atmospheric attain charges considerably greater than 3×10^{-4} coulomb/cm^2.

45. CRYSTAL STRUCTURE AND ELECTRICAL PROPERTIES OF LONG-CHAIN COMPOUNDS

Kakiuchi, Y.
***Institute of Physical and Chemical Research, Scientific Papers of the*, Tokyo, v. 40, pp. 189–200, 1943**

An electrical charge is released when certain long-chain compounds solidified from their melts under an electric field are warmed again. Type-A compounds, such as paraffins, acids, and esters, produce no current; type-B compounds, such as alcohols, halides, and amides, show a considerable peak in the current–temperature curve. In the X-ray study, there were observed two rings having intensity maximum in the direction of the field for the type B; the inner ring is enhanced in the direction of the field and the outer ring in the direction perpendicular to the electric field for the type A. Hence type-A

compounds have no electric moment; it is canceled by the H bonds for aliphatic acid, or by alternate arrangement along their long chains for esters. (*CA*, 1947, #6093g)

46. EXPERIMENTS ON ELECTRETS

Gross, B.
***Physical Review, The*, v. 66, pp. 26–28, July 1–15, 1944**

An investigation of the currents and charges in electrets is described, preceded by a study of the influence of temperature on dielectric absorption, since the preparation of an electret usually involves a heat treatment. The basis of the discussion is the postulate of the existence of homocharges and heterocharges, the former being the true (surface or space) charge, of the same sign as the polarizing electrodes, and the latter the true charges of the contrary sign. Regarding an explanation of electret behavior, it is considered that two mechanisms act simultaneously: (1) dielectric absorption, related to the movement of ions or the orientation of dipoles in the interior of the dielectric, originates heterocharges, and (2) conduction in the interphase dielectric-electrode, which originates homocharges. (*PA*, 1944, #2599)

47. THE ELECTRETS

Sanchez, A. E.
***Anales de fisica y quimica*, Madrid, v. 40, pp. 725–737, 1944**

Only those electrets of the Eguchi type, which contain dipolar molecules, show for a long time intense charges on their surfaces, after the polarization curve has gone beyond the time axis and consequently the sign of the charges has been inverted. The Nadzhakoff photoelectret, produced by the action of an external electric field, varying the conductivity of the S when illuminated, shows only slight polarization in darkness. With the present electrets, formed by the action of an electric field on the interface S-wax (presumably due to van der Waals forces), polarization of the S appears to follow the characteristic course with time, without inversion of the sign of the charge. The Gemant test, with respect to inversion of the sign of the charge in the Eguchi electrets containing polar molecules within five days after its separation, is confirmed and appears to be a piezoelectric effect. From graphs, it is probable that the process is reversible when the limit of elasticity of the dielectric is not exceeded. The paraffin electret of the Eguchi type, with nonpolar molecules, remains slightly polarized for a long time, without showing inversion of charges or piezoelectric effect. A glass plate, when subjected to the action of an electric field, remains polarized only a few minutes, the polarization curve converging asymptotically toward the time axis. (*CA*, 1956, #6604h)

48. ON PERMANENT CHARGES IN SOLID DIELECTRICS. I—DIELECTRIC ABSORPTION AND TEMPERATURE EFFECTS IN CARNAUBA WAX

Gross, B., Denard, L. F.
***Physical Review, The*, v. 67, pp. 253–259, April 1–15, 1945**

Isothermic and nonisothermic current–time curves are measured. It is shown that a considerable part of the absorbed charge can be frozen in, if the temperature is reduced to a value sufficiently inferior to that prevailing during the charging period before the system is short-circuited. The frozen charge dissipates extremely slowly, if the temperature is kept low, but it is liberated rapidly if the temperature is raised again. The effect is explained by the increase of the charging and discharging rates with increasing temperature. It is closely related to the permanent moment of the electret. (*PA*, 1945, #1831)

49. A SEARCH FOR PIEZOELECTRICITY AS A CAUSE OF ELECTRET BEHAVIOR

Clark, E. L.
1947
Kansas, University of, Lawrence
Thesis

50. FORCES BETWEEN MAGNETS AND BETWEEN ELECTRETS

Eldridge, J. A.
***American Journal of Physics*, v. 16, pp. 325–335, 1948**

The correct relations are developed for forces between magnets; these also apply to forces between electrets, or permanently polarized dielectrics such as a piezoelectric crystal under strain. (*CA*, 1956, #8035c)

51. THE ELECTRET

Gutmann, F.
***Reviews of Modern Physics*, v. 20, pp. 457–472, July 1948**

Substances capable of permanent electrification are classified, with details of their thermal and electrical preparation. This is a comprehensive survey, including 14 figures and 47 references to the literature prior to 1946.

Factors affecting the magnitude of the surface charge and the permanency of electrification are discussed. Present theories of the electret are shown to be inadequate; the author considers that Gemant's ionic theory gives the best explanation for the formation of heterocharge (charge on the electret of opposite sign to the polarizing electrodes) while conduction currents in the interface between electrode and dielectric produce the homocharge (charge of the same sign as the "forming" electrodes). There is no explanation for the photoelectret. Practical applications are briefly discussed. (*PA*, 1949, #6191)

52. **ON THE CARNAUBA WAX ELECTRET**
Gross, B.
***Anais da Academia Brasileira de Ciências*, v. 20, pp. 247–253, September, 1948 (in English)**

A systematic study of the permanent surface charges which lead to the formation of the electret is reported. The current in the external circuit and the charge on one of the electrodes of the capacitor containing the sample are measured during the application of the polarizing field and after withdrawal of the field and short circuiting. This enables the current across the interface to be split into its two components, viz., exchange of charge carriers (conduction current) and internal rearrangement of charge and dipole rotation (absorption current). An improved dissectible capacitor is used. The results are shown graphically and demonstrate the coexistence of the two types of charges. These may have opposite polarities and serve to explain the phenomena observed. With a sufficiently high applied voltage, surface breakdown occurs, which causes the transfer of an ionic charge to the surface of the dielectric; with constant voltage the induced charge is seen to undergo discontinuous variations. Calculation shows that the highest field which can be achieved under the experimental conditions is ~70 kv/cm. (*PA*, 1949, #1897)

53. **ELECTRETS**
Gemant, A.
***Physics Today*, v. 2, p. 8, March 1949**

54. **CERAMIC ELECTRETS**
Dickinson, T. A.
Ceramic Industry, v. 52, no. 5, pp. 62–64, 1949

Applications of glass and ceramic electrets to mass spectrometers, electrometers, batteries, and microphones are proposed. (*CA*, 1956, #6798h)

55. **PERMANENT CHARGES IN SOLID DIELECTRICS. II—SURFACE CHARGES AND TRANSIENT CURRENTS IN CARNAUBA WAX**
Gross, B.
***Journal of Chemical Physics*, v. 17, no. 10, pp. 866–872, October 1949**

Permanent surface charges are produced in disks of carnauba wax by exposure to an external electric field. The nature of these charges is studied with a new method of analysis, which is based on the simultaneous measurement of the external current and of the induced charges on the electrodes of the capacitor containing the dielectric. The observed effects are explained by dielectric absorption and by transfer of charge from the electrode to the surface of the dielectric; this latter phenomenon is due to surface breakdown and continuous conduction currents. The results provide an adequate explanation for the electret. (*CA*, 1956, #2302h)

56. **FIZIKA DIELEKTRIKOV (PHYSICS OF DIELECTRICS)**
Skanavi, G. I.
Gosudarstviennoye Izdatelstvo Tekhniko—Teoreticheskoy Literatury, Moscow–Leningrad, 1949 (in Russian)

It was shown that the value of polarization current rises with increase of initial polarization temperature.

57. **HETEROCHARGE**
Franklin, A. D.
***Physical Review, The*, v. 78, p. 342, 1950**

A short review is given of a paper presented at the American Physical Society Meeting held in New York City, February 2–4, 1950.

58. **ELECTRETS**
Swann, W. F. G.
***Physical Review, The*, v. 78, pp. 811–812, June 15, 1950 (Letter)**

A one-dimensional mathematical treatment of the problem of charge storage by electrets is given, assuming that electrets consist of (1) a distribution of semipermanent polarization which changes with time, and (2) a distribution of surface and volume charge which disappears according to ohmic conductivity, and has no relation to the decay of the polarization. (*PA*, 1950, #7966)

59. AN APPARATUS FOR THE STUDY OF ELECTRETS

Freedman, L. A., Rosenthal, L. A.
***Review of Scientific Instruments, The*, v. 21, pp. 896–898, 1950**

A vibrating plate type of induction voltmeter for observing the charge of electrets is described.

60. ON CERTAIN MATTERS PERTAINING TO ELECTRETS

Swann, W. F. G.
***Franklin Institute, Journal of the*, v. 250, pp. 219–248, September 1950**
(See also Proceedings of the American Physical Society Meeting, Washington, D. C., April 27–29, 1950)

The object is to trace the mathematical consequences of the assumption that an electret consists of: (1) a distribution of polarization which decays with time, and (2) a distribution of surface and volume charge which disappears according to ohmic conductivity having no relation to the decay of the polarization. The electret is supposedly provided with metal plates permanently attached to its surface and to have a thickness of 1 cm and a radius of 3 cm. Starting with one plate at zero potential and the other at a negative potential V_0, symbolizing in the ordinary terminology the condition in which the electret shows a "heterocharge," the absolute value of V decays with time to zero. It then rises to a positive maximum, after which it again decays with time, ultimately to zero. The functional relation between potential difference and time is independent of the charge distribution within the electret and of its decay. The only parameters involved are the resistance R connecting the plates and the parameter determining the rate of decay of the polarization. However, while the initially produced polarization plays a part in determining the maximum positive potential V_m attained and while V_0 plays a part in determining the time for the potential to change from V_0 to zero, neither of these quantities plays any part in determining the subsequent time for rise to the maximum V_m. If the resistance is such as would be determined by ordinary ohmic conductivity in a substance of the normal specific resistance of a wax, if the polarization decays according to a factor $e^{-\alpha t}$, and if α is 10^{-8} sec^{-1}, corresponding to a decay of the polarization to $1/e$ of its initial value in about three years, then, starting with $V_0 = -2000$ v and with the initially produced polarization such as to make $V_m = 2000$ v, there results the following: V will change from its original value -2000 v to zero in about 1½ days, then it will rise to the positive maximum V_m in about two weeks, after which it will decay to one-third of that maximum value in about three years.

If the electret be exposed to the open air, the conductivity of the air would produce a smaller resistance than the wax itself, and the maximum would be attained in about 42,000 seconds after the value $V = 0$ was reached.

If, with the conductivity of the wax alone operating in determining R, we desire a maximum value of V equal to 2100 v, it would only be necessary to have an initial polarization less than one percent of that which would be produced by a complete orientation of the dipole moments of the molecules of the wax in one direction.

Expressions are also developed for the case where the charge within the electret disappears by self-repulsion to the plates, in addition to its decay by ohmic conductivity. Such a phenomenon can, of itself, simulate a decaying polarization.

A discussion of experiments pertaining to the field outside of the electret is also given. (*PA*, 1951, #1045)

61. STATIC CHARGES ON DIELECTRICS

Gross, B.
***British Journal of Applied Physics*, v. 1, pp. 259–267, October 1950**

The author has previously shown the permanent "homo" charge (of the same sign of the electrode) on electrets arises from a transfer of charge from electrode to dielectric surface, often by discharges. Using the method of the demountable capacitor, this discharge process of charge transfer has been investigated on polystyrene. By assuming that breakdown occurs at a given inception voltage, persists until the voltage drops to an extinction voltage, and affects the whole area of the electrode and dielectric surface, a quantitative explanation has been given of the variation of the charges on the electrode and on the dielectric surface when the voltage is varied in steps, in cycles, continuously and alternating. The explanations agree with the current theories of internal and external discharges. The extinction voltage is found to be not much less than the inception voltage, as opposed to the low extinction voltages sometimes or often encountered in internal discharges. (*PA*, 1950, #296)

62. ELECTRIFIED CERAMICS
Dickinson, T. A.
Ceramic Age, v. 57, no. 3, pp. 17, 18, 38–39, 1951

Materials for electrified ceramics can be fabricated as usual and fired at about 2500°F. They are then charged with high-voltage current of from 4000 to more than 20,000 v/cm. At temperatures below the Curie point, dissipation of electrification can be prevented through the use of metallic keepers. (*CA*, 1956, #7765i)

63. THE NOISE OF DECAYING ELECTRETS
Kojima, S., Kato, K.
Physical Society of Japan, Journal of the, v. 6, p. 207, May–June, 1951 (Note)

Barkhausen noise is observed during the decay of homocharge, but not during the decay of heterocharge. (*PA*, 1951, #8724)

64. ON THE ELECTRET
Kakiuchi, Y.
Physical Society of Japan, Journal of the, v. 6, pp. 278–279, July–August 1951 (Note)

Of the separated components of Eguchi's electret mixture of carnauba wax and resin, only the free wax alcohols show strong electret properties, although mixtures of the other components, e.g., esters and abietic acid, are weak electrets. (*PA*, 1952, #4336)

65. THE PERMANENTLY POLARIZED DIELECTRIC
Binder, F.
Zeitschrift für Naturforschung, v. 6a, pp. 714–718, November 1951 (in German)

The concept of the electret formulated by Heaviside and first demonstrated by Eguchi is discussed and illustrated by measurements on polyvinyl chloride using a demountable capacitor. Confirmation that the homocharge is formed by discharges between the electrode and the dielectric surface is provided by dusting the surface with suitable powders. The patterns show that the surface is not uniformly charged. Possible applications of electrets are briefly discussed. (*PA*, 1952, #1774)

66. ELECTRET-LIKE BEHAVIOR IN POLARIZED BARIUM TITANATE CERAMIC
Thickens, R. W., MacDonald, R. J.
Physical Review, The, v. 90, p. 375, 1952

A summary is given of a paper presented at the American Physical Society Meeting held at Cambridge, Massachusetts, January 22–24, 1953. (*CA*, 1954, #7945a)

67. ELEKTRETE (ELECTRETS)
Euler, J.
Zeitschrift des Vereines Deutscher Ingenieure, v. 94, no. 16, pp. 481–483, June 1, 1952
(See also Report ATI-153800)

The similarity between magnetic materials and electrets is shown. The reason why a dielectric material becomes an electret must be that it is made up of separate space charges. However, when the surface is scraped off, the dielectric charge is not lost. In some electrets polarity is maintained indefinitely, whereas in others polarity reverses in time, the reversal time being dependent upon the formation field intensity. Up to 30 kv/cm the surface charge is proportional to the formation field intensity. Some practical applications for electrets, e.g., in electrometers, are discussed.

68. AN AUTOMATIC CHARGE MEASURING AND RECORDING APPARATUS
Feaster, G. R., Prosser, F. W., Wiseman, G. G.
Review of Scientific Instruments, The, v. 23, pp. 763–764, 1952

An apparatus for automatically recording the charge of several electrets at periodic intervals over long periods of time is described.

69. STUDIES IN ELECTRETS. I
Bhatnagar, C. S., Bhawalkar, D. R.
Indian Academy of Sciences, Proceedings of the, Section A, v. 36, pp. 170–174, September 1952

The steady-current characteristics of carnauba wax were studied with the view to understanding the mechanism of formation and properties of electrets. Careful investigations showed that the "hysteresis effect" was totally absent in steady currents observed while cooling and heating carnauba wax under the influence of an electric field. The electric field was varied from a few volts to 10 kv/cm. The rate of change of current with temperature is very small below 75°C for all voltages and increases very rapidly for higher temperatures up to the melting point. Beyond the melting point the rate again falls. (*PA*, 1954, #431)

70. THE HEAT CONDUCTIVITY OF ELECTRETS

van Calker, J., Arnold, R.
***Zeitschrift für Physik*, v. 132, pp. 318–329, 1952**

A number of pure waxlike triglycerides were allowed slowly to solidify in a tub-shaped metal box with long parallel sides while an almost uniform electric field of 30 kv/cm was applied horizontally across the small dimension. After electrets had thus been formed, the heat conductivity depended on the electric field. Since completely dehydrated waxes do not show this effect, it is ascribed to water droplets frozen in the wax under the influence of the field. (*CA*, 1956, #9964a)

71. TEMPERATURE-RELATION OF VARIATIONS OF THE PHOTO-ELECTRETS

Nadzhakov, G., Kashukeev, N. T.
***Izvestiya na Bulgarskata Akademiya na Naukite*, v. 3, pp. 103–115, 1952; published 1954 (in Bulgarian, with summaries in Russian and German)**

Investigations on the variations of the photo-polarization due to temperature variations of photo-electrets are presented. It was found that the main causes of these variations are a decrease of the photo-polarizability and an increase of the recombination of the space charges of opposite sign, and also an increase of the diffusion of the charges of photo-polarization in the direction of the electrodes. At low temperatures both processes occur at a very slow rate and the polarization either remains practically unchanged or decreases very slowly. (*PA*, 1955, #4629)

72. PLASTIC ELECTRETS

Wieder, H. H., Kaufman, S.
***Journal of Applied Physics*, v. 24, pp. 156–161, February 1953**

A brief discussion of proposed explanations for the electret effect is presented. Plexiglas, lucite and nylon electrets were prepared under fields ranging from 19 to 36 kv/cm and observed for as long as 2000 hr. The surface charge densities were measured by electrostatic induction, using a commercial electronic electrometer and a shunt capacitance to reduce the readings to a maximum of 20 v. The initial state was a heterocharge or a homocharge, depending on the strength of the forming field. The steady state was a homocharge in every case. Charge densities as high as 5.5×10^{-9} coulomb/cm^2 (16.5 esu) were observed. A plexiglas disk was charged at room temperature under a strong field and its subsequent decaying homocharge recorded. The experimental results support the ideas of Mikola and Gross, i.e., the existence of two decaying polarizations of opposite sense due to ionic migration, one occurring within the dielectric, the other across the electrode-dielectric interface. (*PA*, 1953, #3287)

73. STUDIES OF THE HETEROCHARGES OF ELECTRETS

Wikström, S.
***Arkiv för Fysik*, v. 7, Paper 20, pp. 213–220, 1953 (See also *Ericsson Technics*, v. 9, no. 2, pp. 225–234, 1953)**

Heterocharged electrets of carnauba wax have been studied from the following points of view: the dependence of the charging and discharging rate on temperature; influence of a dc field at room temperature on a prepared electret; influence of pressure during charging and discharging; influence of polarization on the ac capacitance and loss angle. (*EEA*, 1954, #2041)

74. FUNDAMENTALS IN THE BEHAVIOR OF ELECTRETS

Swann, W. F. G.
***Franklin Institute, Journal of the*, v. 255, pp. 513–530, June 1953**

The paper cites certain results of an earlier paper by the writer in which are traced the consequences of the assumption that an electret is characterized by a state of polarization, semipermanent in the sense that it decays very slowly with time. The decay takes place under the influence of an ohmic conductivity.

The behavior of the dielectric in the case of an exponential decay is determined by the initial polarization P_0, which may vary across the electret; the initial potential difference V_0 between the surfaces of the electret; the coefficient, α, in the exponential decay; and the quantity RC representing the product of the resistance and capacity associated with the electret.

In the present paper it is demonstrated that, in the case of an electret which shows a maximum in the curve representing potential difference between surfaces plotted against time, all of the foregoing quantities may be obtained from measurements of the initial potential difference, the maximum potential difference, the time for the potential difference to fall to zero, and the time for it to attain its maximum. The theory of the matter is extended to the case where the semipermanent polarization is represented by a finite or infinite number of contributions, each having its own particular relaxation time.

The question of what determines the initial potential difference after the electret is removed from its forming plates is discussed. It is shown that a reasonable understanding of the facts can be obtained qualitatively and quantitatively by assuming that on separating the plates slightly from the surfaces of the electret, the charge densities retained by the plates are limited by the condition that the resulting field in the air space is less than the breakdown field in air, at the moment of separation.

75. PLASTIC ELECTRETS AND THEIR APPLICATIONS

Wieder, H. H., Kaufman, S.
***Electrical Engineering*, v. 72, no. 6, pp. 511–514, 1953**

The electret effect in high-polymer plastics is described and compared to published data on the behavior of wax electrets. The results indicate the existence of large ionic polarizations, giving rise to an essentially constant external electric field. Some engineering applications of electrets are discussed and limitations presented in terms of current knowledge of electret phenomena.

76. INVESTIGATION OF LASTING POLARIZATION PROCESSES IN GLASS AT TEMPERATURES UP TO 70°C

Kosman, M. S., Paranyuk, R. T.
***Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 24, no. 6, pp. 721–729, 1953 (in Russian)**

Presents graphed results of investigations on the electric properties of glass at room temperature, conducted by using the following methods: (1) transverse electric field applied to Te films (on mica and glass); (2) self-discharge of the individual elements of an equivalent system; (3) direct determination of the polarization capacities; and (4) probe measurements. It has been found that charges induced on condenser plates may decrease although polarization charges in the dielectric remain unchanged; the transverse-field method enables the lasting polarization processes to be determined in glass at relatively low temperatures (17–47°C); and the conductivity of both the glass and α-Ag_2S may be of electronic nature because the large low-voltage polarization capacities revealed cannot be attributed to ionic processes. (*PA*, 1954, #11035)

77. THE CASE OF CHARGED DENSITY DISTRIBUTION VERSUS SEMI-PERMANENT POLARIZATION AS A BASIS FOR ELECTRET BEHAVIOR

Swann, W. F. G.
***Franklin Institute, Journal of the*, v. 256, pp. 167–176, August 1953**

A distribution of volume and surface charge densities of total amount zero is the equivalent, in regard to the field produced, of a suitably chosen distribution of polarization. A formal proof is given. The distribution of polarization lacks uniqueness to the extent of any contribution which, considered as a vector, is not derivable from a potential. It is shown that, if an electret were composed of ordinary charge distributions, its effects would diminish by 50 percent in one to two days on the basis of any reasonable assumption for the conductivity of the medium. Electret behavior must thus be based upon assumption of a semipermanent polarization decaying in a manner independent of conductivity. The effects observed can be regarded as arising from a lag in the action of conductivity in providing for a cancellation of the effects of polarization at each instant. An explanation is given of the fact that the polarization, regarded as a submacroscopic distribution of charges, is itself not annihilated by the conductivity with a time constant appropriate thereto. (*EEA*, 1954, #1060)

78. ELECTRETS

Wiseman, G. G., Linden, E. G.
***Electrical Engineering*, v. 72, no. 10, pp. 869–872, October 1953**

Electrets are discussed from the viewpoint of their measurement, materials from which they can be made, theories concerning their formation, and practical applications. It is concluded that the sign of the electret charge depends not only on chemical composition and structure, but also on electrical and thermal treatments.

79. ELECTRET

Yamanaka, C.
***Physical Society of Japan, Journal of the*, v. 9, no. 3, p. 425, May–June 1954 (Note)**

The behavior of carnauba wax electrets depends on the amplitude of the "forming" voltage. (*PA*, 1955, #924)

80. ELECTRETS AND THEIR APPLICATION IN ELECTRICAL ENGINEERING

Nazarov, V. G.
***Elektrichestvo*, no. 7, pp. 60–62, 1954 (in Russian)**

An account of the discovery of electrets and classic investigations by Sato Eguchi and Kurchatov introduces

a brief and concise survey of the characteristics, and present and possible future applications of these devices, followed by information on their production. (*EEA*, 1958, #257)

81. ELECTRETS

Keller, K. J.
***Electrotechniek*, v. 32, pp. 289–294, July 29, 1954 (in Dutch)**

Explains their physical properties and the method of production. The possible practical application of electrets to an electrostatic high-voltage generator, ac generator, electrostatic calculator, electrometer condenser-microphone, and high-voltage voltmeter are outlined. (*EEA*, 1954, #5083)

82. THE ORIGIN OF HOMOCHARGE IN NAPHTHALENE ELECTRETS

Baldus, W.
***Zeitschrift für angewandte Physik*, v. 6, no. 11, pp. 481–489, 1954 (in German)**

An account of apparatus for preparing electrets under controlled conditions using metallic and nonmetallic electrodes, with details of the variation with time of the heterocharge and homocharge and the magnitude of the homocharge at different depths below the surface. The space-charge distribution in the interior of electrets is discussed theoretically. (*EEA*, 1955, #1116)

83. ELECTRICAL NOISE PULSES FROM POLARIZED DIELECTRICS

Baumann, N. P., Wiseman, G. G.
***Journal of Applied Physics*, v. 25, no. 11, pp. 1391–1394, November 1954**

Electrical noise pulses have been observed at elevated temperatures in polarized dielectrics (electrets) made of carnauba wax and of a vinyl acetate polymer. Pulse rate vs. time was observed for electrets heated at a uniform rate and the results differ from those previously reported by others. Experiments devised to determine the origin of the pulses indicate that they are associated with the decay of volume polarization rather than with real surface charge. The total charge associated with the pulses from carnauba wax electrets is at least five percent of the maximum electret charge. (*PA*, 1955, #1797)

84. ABNORMAL INCREASE IN THE DIELECTRIC CONSTANT OF AN ELECTRET-FORMING MATERIAL

Chatterjee, S. D., Bhadra, T. C.
***Physical Review, The*, v. 98, no. 6, pp. 1728–1729, June 15, 1955**

An electret with its two surfaces covered by plates which are connected together presents a situation in which the average (zero) field between the plates is composed of two equal and opposite parts, one due to the polarization and the other due to the charges on or adjacent to the plates. These opposing fields can be very large ($\sim 10^6$ v/cm) and as a result, large fluctuations may be expected in the vicinities of individual molecules. For these reasons it is surmised that the permittivity of the material of an electret may show an abnormal value, depending upon "strength" of the electret. The experiments described confirm the existence of such an abnormality. (*EEA*, 1955, #3687)

85. THE MECHANISM OF SOME ELECTRETS

Antenen, K.
***Zeitschrift für angewandte Mathematik und Physik*, v. 6, no. 6, pp. 478–484, November 25, 1955 (in German)**

Probe measurements of the potential distribution within carnauba wax electret specimens are reported. The nonuniform distribution found provides proof of the author's contention that the heterocharge in electrets is due not to dipoles, but to ionic space-charge layers near the electrodes. Reasonable values for the ion concentration and mobility are derived. Electrets were also made from paraffin wax containing small amounts of impurities. (*PA*, 1960, #18106)

86. EXPERIMENTS ON THE CARNAUBA WAX ELECTRET

Gerson, R., Rohrbaugh, J. H.
***Journal of Chemical Physics*, v. 23, no. 12, pp. 2381–2388, December 1955**

The strength of the applied electric field, the thickness of the slab being electrified, the time of electrification, and the low-temperature holding time before removing the field were varied for carnauba wax electrets. After approximately one hour the discharge current varied inversely as a power of the time since turning off the forming field, the power being close to one. The magnitude of this current depended on both the forming

field strength and on the thickness of the electret. A very large discharge was obtained when the wax was electrified and discharged while not completely solid. Dielectric constant measurements were made at temperatures between 27 and 86°C, frequencies between 50 cps and 13 kc, and with superposed dc field strengths in the wax of zero, 3700 and 8100 v/cm. The application of dc field was found to raise the dielectric constant at the higher temperatures. The case for permanent dipole orientation and that for ionic space charges as the cause of the stored charge of the electret was examined, and it is shown that there are objections to each mechanism. An alternate explanation is suggested. (*PA*, 1956, #2071)

87. REVERSAL IN THE MAGNETIC SUSCEPTIBILITY OF AN ELECTRET-FORMING MATERIAL

Chatterjee, S. D., Sutradhar, N. G.
***Naturwissenschaften*, v. 42, no. 12, p. 366, 1955**

In recent work Chatterjee and Bhadra found an abnormal increase in the dielectric strength of an electret-forming carnauba wax. A graph is given for a small cylindrical electret of carnauba wax showing that after formation of the electret the magnetic susceptibility first rises to nearly 6×10^{-7} in 12 days, then drops gradually to the original value of -4×10^{-7} in 45 days and remains at a constant negative value. This behavior confirms the liberation of electrons from polarized molecules during a state of high field perturbation. The liberated electrons are, however, only semifree. Calculations indicate that in the case of carnauba wax roughly five electrons are free per molecule to account for the susceptibility. (*CA*, 1956, #11744i)

88. ELECTRICAL CONDUCTIVITY OF CARNAUBA WAX WHEN DIFFERENT ELECTRODES ARE USED

Bhatnagar, C. S., Bhawalkar, D. R.
***National Academy of Sciences, Proceedings of the*, India, Section A, Part 1, v. 25, pp. 20–24, 1956**

The variation of conductivity (I) of carnauba wax (II) with temperature between 70 and 95° was studied with electrodes of Sn, Ni, and Cu. I increased slowly up to 80° and then rose sharply up to 83°. This range of 80–83° is the temperature of transition from solid to liquid for II. I differed with each electrode. I was smallest in the solid state with Sn. This effect parallels the fact that Sn electrodes produce the best electret with II. A dc potential of 150 v was applied to the electrodes. (*CA*, 1957, #10147h)

89. HETERODISCHARGE OF ELECTRETS OF CARNAUBA WAX

Froiman, A. I., Fridkin, V. M.
***Kristallografiya*, v. 1, no. 3, pp. 342–350, 1956**

The change in the magnitude of the heterodischarge for an electret of carnauba wax with the strength of the polarizing field and the temperature of polarization was determined. For electric field strengths in the range 2.1–12 kv/cm there is a linear relation between the heterodischarge and field strength. The formation of the heterodischarge has an activation nature. The corresponding energy of activation is 18,500 cal/mole. (*CA*, 1957, #7786i)

90. ELECTRICAL CHARACTERISTICS OF THIN ELECTRETS PREPARED FROM CARNAUBA WAX

Bhatnagar, C. S., Bhawalkar, D. R.
***Sauger University Physical Society, Research Bulletin of the*, India, v. 1, no. 1, pp. 10–13, April 1956**

Dependence of electric charge on the thickness and the polarizing field has been investigated for electrets prepared from carnauba wax. The results show that for electrets of thickness less than 0.1 cm, the charge per unit area is constant for fields above 1 kv/cm. Electrets above 0.1 cm thickness show a charge 30 percent higher if the polarizing field is above 10 kv/cm. These results are the same for the three varieties of carnauba wax used. (*PA*, 1957, #4308)

91. THE CHARGES ON ELECTRETS

Palm, K.
***Experimentelle Technik der Physik*, v. 4, no. 6, pp. 253–262, 1956 (in German)**

The surface charges which remain after cooling the samples in an electric field were measured for PVC, polymethylmethacrylate and polystyrene. Heterocharges were found with the two former materials, homocharges with the latter. Plots of charge density against time are shown for a number of polarizing field strengths. The effects are explained quantitatively in terms of frozen-in dipole orientation (heterocharge) and charge transfer from the electrodes (homocharge). (*PA*, 1959, #1425)

92. NO TITLE
Skanavi, G. I.
Tomsk Politekhnecheskii Institut, Izvestia, v. 91, p. 219, 1956

Polycrystalline inorganic insulators (ceramic insulators) are considered.

93. ELECTROPHOTOGRAPHY ON PHOTOELECTRETS
Fridkin, V. M.
Kristallografiya, v. 2, pp. 130–133, 1957

On the basis of previous studies of photoelectric phenomenon in polycrystalline S, a method was developed for obtaining images on the photoelectret surface. A thin layer of S was vacuum deposited on Al or Zn plate. During the deposition process S was polarized under constant illumination (2.5 min) and applied potential. Gold-coated quartz served as a semitransparent electrode. The surface charge of the photoelectret was measurable with a dynamic electrometer (diagram of the circuit given). A slide containing a printed image was placed on the surface and the photoelectret was exposed to light. Depolarization occurred only within the illuminated area. The invisible replica of the image was developed by means of the triboelectric effect: the surface was covered with the mixture of powdered sand and NaCl; and depending on the sign of the charge in the S layer, the replica of the image appeared traced either by sand or NaCl (photographs of the photoelectret given). The electrophotography on the photoelectret was considered to be analogous to magnetic type recording, and the practical applications of the photoelectret were briefly discussed. (*CA*, 1958, #1774i)

94. NEW ELECTRETS FROM INORGANIC DIELECTRICS
Gubkin, A. N., Skanavi, G. I.
Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki, v. 32, no. 1, pp. 140–142, 1957 (Translated from the Russian in *Soviet Physics–JETP*, v. 5, pp. 140–143, 1957)

It is shown that stable electrets can be obtained from polycrystalline inorganic dielectrics, such as the titanates of magnesium, calcium, bismuth, strontium, zinc, strontium-bismuth, from barium metatitanate, barium tetratitanate and from steatite. Results are presented giving the variation of the effective surface density of charge with time. (*PA*, 1957, #6155)

95. SOLIDIFICATION OF PARAFFIN WAX IN AN ELECTRIC FIELD AND ITS CORRELATION TO THE ORIENTATION OBSERVED IN ELECTRETS
Chandy, K. C., Bhawalkar, D. R.
Saugar University Physical Society, Research Bulletin of the, India, v. 2, no. 1–2, pp. 39–44, 1957

Solidification of paraffin wax under high dc fields in two different types of apparatus was studied using X-ray diffraction techniques. Except for a few cases of slight variations of density at some regions of the circumference of the diffraction rings, no clear orientation pattern was obtained. This is contrary to the reports of Bennet and of Kakiachi. However, the result is in accord with theoretical predictions, in that the nonpolar hydrocarbons in paraffin wax cannot be expected to orient in a high dc field. Explanations are given for the weak and random variations of density of the diffraction rings observed in some of the patterns. (*PA*, 1959, #5863)

96. EXPERIMENTS ON THE POLARIZATION AND DECAY OF ELECTRETS
Wiseman, G. G., Feaster, G. R.
Journal of Chemical Physics, v. 26, no. 3, pp. 521–527, March 1957

Experiments were made to test implications of the two-charge theory of electrets of Gross. The theory was confirmed and extended. The persistent volume polarization of a number of dielectrics can be expressed by analytical functions that are linear in the applied field and exponential in time. The linear superposition of the effects of homocharge and heterocharge was demonstrated for some dielectrics and was shown to be violated for lucite. The heterocharge and homocharge were different but interacting entities, their interaction being given by the static field equations for a three-layer capacitor. A major cause of electret decay is the self-polarization of the electret by its own electric field. (*CA*, 1957, #10149c)

97. X-RAY DIFFRACTION PATTERN OF ELECTRETS
Chandy, K. C., Bhawalkar, D. R.
University of Saugar, Journal of the, India, Part II, Section A, v. 6, no. 6, pp. 84–89, 1957

Electrets were prepared from carnauba wax containing no added matter. X-ray diffraction patterns were obtained from: (1) electrets prepared by the usual method; (2)

extraneous wax detached from the electret, and (3) wax obtained after remelting the electret. Three types of carnauba wax were used for this purpose: fatty gray, refined fatty gray, and prime yellow. Distinct orientations were noticed with electrets prepared from the prime yellow variety, while the other two varieties showed very feeble orientations. Besides the normal rings extra rings were observed in certain patterns, which are assigned to the silica present in the wax. (*PA*, 1959, #6895)

98. IRRADIATION EFFECTS IN BOROSILICATE GLASS

Gross, B.
***Physical Review, The*, v. 107, pp. 368–373, July 15, 1957**

Thick borosilicate glass irradiated by high-energy electrons acquires slow-decaying space charges and exhibits electret behavior in inducing adjacent conductor charges and in giving short-circuit discharges on heating. The glass contains a negative electron arrest charge and a positive compensation charge. (*CA*, 1958, #1570b)

99. EXPERIMENTS ON ELECTRETS

Polovikov, F. I.
***Elektrichestvo*, no. 9, pp. 58–59, 1957 (in Russian)**

Preparation of electrets is briefly described. Relevant data are given for the following materials: paraffin, naphthalene, sulfur, ebonite and plexiglas. (*EEA*, 1958, #1324)

100. THE PHENOMENOLOGICAL THEORY OF ELECTRETS

Gubkin, A. N.
***Zhurnal Tekhnicheskoi Fiziki*, v. 27, no. 9, pp. 1954–1968, 1957 (Translated from the Russian in *Soviet Physics—Technical Physics*, v. 2, no. 9, pp. 1813–1824, September 1957)**

Adams' and Swann's phenomenological theories were developed for short-circuited electrets. It is shown that only when shortcircuiting is allowed for can the phenomenological theory give results describing the experimental data for electrets made from carnauba wax correctly. The theory developed here is also extended to new electrets made from inorganic insulators with electrical conductivities considerably higher than that of carnauba wax. The analysis shows that the electret lifetime can be defined as $1/4\pi M$, where M mainly depends on the electret conductivity, the surrounding medium and the short-circuiting conditions, and on $1/\alpha$, where α is a parameter specifying the time rate of fall of the semiconstant polarization. The values of $1/4\pi M$ and $1/\alpha$ are calculated for several electrets, as are the heterocharge and homocharge magnitudes. It is shown that in most cases the electret lifetime is determined by $1/4\pi M$. (*PA*, 1959, #4557)

101. THE ANOMALOUS STABILITIES OF NEW INORGANIC POLYCRYSTALLINE ELECTRETS

Gubkin, A. N., Skanavi, G. I.
***Zhurnal Tekhnicheskoi Fiziki*, v. 27, no. 9, pp. 1969–1970, 1957 (Translated from the Russian in *Soviet Physics—Technical Physics*, v. 2, no. 9, pp. 1825–1826, September 1957)**

Previously stated conditions for storing electrets so as to maintain the charge over long periods are briefly reviewed. Electrets made from ceramic materials have been found to retain the majority of their charge without the need for short-circuiting them with metal foil. Results are given for the variation of homocharge on calcium titanate electrets stored in both the "short-circuited" and "open" conditions for a period of eight months. The electrets had specific conductivities of 10^{-12} to 10^{-14} ohm^{-1} cm^{-1}, and so in the "open" condition they should have discharged completely within a few minutes. (*PA*, 1959, #5664)

102. INFLUENCE OF EXTERNAL TREATMENTS ON ELECTRET BEHAVIOR

Wild, J. W., Stranathan, J. D.
***Journal of Chemical Physics*, v. 27, no. 5, pp. 1055–1059, November 1957**

The following effects have been observed:

1. When the surface of an electret which exhibited a homocharge was planed in a lathe, the sign of the equivalent surface charge changed to that of the heterocharge. This heterocharge then decayed and the homocharge finally became dominant again. The magnitude of the final homocharge was smaller than that of a control electret which was not planed.
2. Repeated planing of an electret, with time allowed for recovery between successive planings, resulted in repetition of the cycle described above.

3. Wax dummies (not subjected to an electric field during manufacture) which were given a frictional charge and then planed, showed no reversal of sign; they did exhibit a small recovery after being planed.
4. Electrets subjected to 100 percent relative humidity exhibited an abrupt decrease in equivalent surface charge. Removal of the moisture resulted in a gradual slight recovery.
5. The curve relating the equivalent surface charge and the logarithm of the pressure of the air surrounding an electret has the same form as the curve of the sparking potential for air vs. the logarithm of the pressure.

Thus, all the treatments described resulted in a decay of the homocharge, followed by a partial recovery upon removal of the disturbing influence. The observed behavior can be explained in terms of the electret mechanism proposed by Gross. (*PA*, 1958, #3977)

103. ANISOTROPIC POLARIZATION OF PHOTOELECTRETS FROM SINGLE CRYSTAL SULPHUR

Zheludev, I. S., Fridkin, V. M.
***Kristallografiya*, v. 3, no. 2, pp. 182–185, 1958 (in Russian)**

Single crystals of supposedly orthorhombic S were polarized in various directions and it was shown that the anisotropic polarization depended on the anisotropic photoconductivity of single crystal S. It is concluded that the S crystals were actually monoclinic and that measurement of photoelectric charge provides a method of investigating the anisotropy of photoconductivity in crystals. (*PA*, 1959, #12226)

104. THE PRODUCTION AND PROPERTIES OF NEW ELECTRETS FROM INORGANIC DIELECTRICS

Gubkin, A. N., Skanavi, G. I.
***Izvestia Akademii Nauk SSSR, Seriya Fizicheskaya*, v. 22, no. 3, pp. 330–342, 1958 (Summary translated from the Russian in OTS: PB 141041T-3, U. S. Dept of Commerce, Washington, D. C.)**

The possibility of forming electrets in inorganic ceramic dielectrics is investigated. The materials which are examined include $MgTiO_3$, $ZnTiO_3$, $BaO \cdot 4TiO_2$, $CaTiO_3$, $SrTiO_3$, $BaTiO_3$, KBr, bismuth strontium titanate, steatite and porcelain. The results are summarized in tables. The optimum conditions for forming are given, and the discharge behavior is investigated. (*PA*, 1959, #12223)

105. INVESTIGATION OF THE ELECTRIC AND OPTICAL PROPERTIES OF POLYMERS FORMING ELECTRETS

Filippova, K. V.
***Izvestia Akademii Nauk SSSR, Seriya Fizicheskaya*, v. 22, no. 3, pp. 343–351, 1958 (Summary translated from the Russian in OTS: PB 141041T-3, U. S. Dept. of Commerce, Washington, D. C.)**

Electrets formed from polymethylmethacrylate are shown to be optically anistropic. The anistropy increases almost linearly with the forming field, but there is a threshold forming time of two to three hours at elevated temperature, below which little anisotropy is induced at any field strength. The character of the electret changes with the mode of formation in a manner which is not correlated with the optical anisotropy, and the optical and electrical properties also relax in a different manner. It is suggested that thermally activated reorientation of the polar $OCOCH_3$ groups is primarily responsible for both effects, but that more of the polymer chain is involved in the optical change, thus accounting for the differences in forming and relaxation. (*PA*, 1960, #1705)

106. PHOTOELECTRET AND THERMOELECTRET STATES IN SULFUR SINGLE CRYSTALS

Zheludev, I. S., Fridkin, V. M.
***Izvestia Akademii Nauk SSSR, Seriya Fizicheskaya*, v. 22, pp. 352–358, 1958**

Plates 1 cm^2 and 1–1.5 mm thick were cut from natural crystals of rhombic S and polished to mirror-like surface. Polycrystalline samples were obtained by melting and recrystallization of the plate. The samples were polarized by illumination and simultaneously a potential difference was applied. In the single crystal the polarization decayed to 0 in 50 hr, whereas the polycrystal conserved 40 percent of the initial charge after 90 hr. The depolarization current (with light on) is proportional to the light intensity, but saturation sets in at 5×10^{-5} w cm^2. The depolarization current depends on the time of illumination. The degree of polarization depends on the temperature, the maximum current being low at $-100°$ and rising to a peak at room temperature. (*CA*, 1958, #12489e)

107. MULTI-COMPONENT ORGANIC ELECTRETS

Yanson, Yu. Ya.

***Izvestia Akademii Nauk SSSR, Seriya Fizicheskaya*, v. 22, no. 3, pp. 359–360, 1958 (Summary translated from the Russian in OTS: PB 141041T-3, U. S. Dept. of Commerce, Washington, D. C.)**

From investigations on a number of mixtures of organic substances the author finds that the best electret is produced from a mixture of 40 percent Brazil wax, 40 percent colophony and 20 percent beeswax. Data are given for the character of this electret with different modes of forming. It is suggested that dipolar orientation, electron injection and internal conduction may make significant contributions to the electret polarization. (*PA*, 1959, #12224)

108. A PIEZOELECTRIC EFFECT IN PHOTOELECTRETS

Zheludev, I. S., Fridkin, V. M.

***Kristallografiya*, v. 3, no. 3, pp. 315–321, 1958 (Translated from the Russian in *Soviet Physics—Crystallography*, v. 3, no. 3, pp. 319–324, May–June 1958)**

A piezoelectric effect in photoelectrets was observed and investigated. The electric charge and the piezoelectric moduli were measured in a photopolarized single crystal of anthracene. Reductions in the charge and in the piezoelectric modulus d_{11} of the single crystal were studied during its depolarization in the dark. Tests show that the piezoelectric effect in photoelectrets may be completely explained by a change in the magnitude of the electric polarization as a result of stress-induced changes in the geometric size of the specimen. (*PA*, 1960, #11747)

109. THE EFFECT OF ELECTRIC FIELD UPON THE STRUCTURE OF THIN FILMS OF SOME DIPOLAR LONG-CHAIN MOLECULES

Harada, K., Sakai, T.

***Memoirs of the College of Science*, University of Kyoto, Section A, v. 28, no. 4, pp. 283–292, May 1958**

The effect of static electric field applied to thin films of stearic acid and octadecyl alcohol upon the structure of the films was investigated by the method of electron diffraction. The electric field was applied when the films were formed by evaporation of solution or by melting. In the case of stearic acid, some definite relation between the orientation of the crystals in the film and the direction of the applied field was found. In the case of octadecyl alcohol, the applied field affected the lattice dimension of the crystals. (*PA*, 1959, #4063)

110. ON THE ELECTROSTATIC CHARGING OF CdS SINGLE CRYSTALS UNDER THE ACTION OF HIGH ELECTRIC FIELDS

Böer, K. W., Kümmel, U.

***Annalen der Physik*, Leipzig, Series 7, v. 2, no. 5–6, pp. 217–224, 1956 (in German)**

Both positive and negative charge accumulations were observed in crystals after a high current was passed through them. The dependence of this charge on the magnitude of the field and the frequency when ac fields were used (both in the dark and with weak illumination) and its independence of the nature of the electrode materials, can all be explained on the basis of a nonhomogeneous bulk conductivity which also gives rise to dielectric (polarization) aftereffects. It is argued that the conduction process at high fields cannot be explained in terms of space-charge limited currents initiated by electron injection from the cathode as stated by Rose and Smith. (*PA*, 1959, #3498)

111. ON THE MAKING OF ELECTRET AND MEASUREMENT OF THE CHANGES OF DIELECTRIC CONSTANT OF A POLARISED ELECTRET FORMING MATERIAL WITH TIME

Bhadra, T. C.

***Indian Journal of Physics*, v. 32, no. 6, pp. 281–296, June 1958**

Electrets were made with commercially available carnauba wax and the influence of voltage and temperature on their formation was studied. Attempts were made to measure the surface charges with an electrometer and variations with time of the dielectric constant ε and tan δ were also measured. On application of the field in the molten condition of the material, only a fraction of the dipoles orient in the direction of the field, a larger portion orient randomly in all other possible directions. Alignment of the dipoles in the parallel direction increases the dielectric constant. More of the dipoles orient in the parallel direction with time due to the field induced by the dipoles, thereby increasing the value of dielectric constant. In the present investigation, abnormally high increase in the value of dielectric constant along the

on recent achievements in this field and on the practical use of the "electrets" in modern life. (*TT*, 1960)

117. FIELD MEASUREMENTS ON ELECTRETS AND STUDIES OF THE FORMATION OF THE HOMOCHARGE

van Calker, J., van der Linde, L.
***Zeitschrift für Physik*, v. 155, no. 4, pp. 413–421, 1959 (in German)**

The field at various distances from the surface of an electret was measured by a small mica probe capacitor. The values were consistent with the measured surface charge, using a formula for the field due to Swann. The origin of the homocharge is believed to lie in direct charge transfer from the electrodes when the small air gap breaks down. Confirmatory experiments are reported. (*PA*, 1960, #235)

118. CERAMIC ELECTRETS

Schleicher, E.
***Experimentelle Technik der Physik*, v. 7, no. 4, pp. 168–181, 1959 (in German)**

Specimens of barium titanate of various thicknesses were polarized, the charge remaining on the electrodes being measured over a period of several months. The effect of various electrode materials and of the method of storage (on open or short circuit) were investigated. It was concluded, by testing very thin plates, that a denser fine-grained surface skin is produced during firing of the ceramic. If this is removed by grinding, the electrode metal may diffuse into the body of the sample. (*PA*, 1960, #2925)

119. EXPERIMENTS ON ELECTRETS OF CARNAUBA WAX AND THE FORMATION OF THEIR HETEROCHARGE

van Calker, J., Fröhlich, W.
***Annalen der Physik*, Leipzig, Series 7, v. 4, no. 1–5, pp. 216–224, 1959 (in German)**

The frozen-in charge was determined by reheating the wax and integrating the reverse current as the charge is released. Charging and polarization currents were also measured. The results are interpreted in terms of a space-charge polarization theory due to MacDonald. The concentration of mobile ions, their mobility and a relaxation time are calculated. (*PA*, 1959, #12225)

120. CONCERNING THE EFFECT OF AN ALTERNATING ELECTRICAL FIELD ON THE FORMING OF ELECTRETS

Polovikov, F. I.
***Fizika Tverdogo Tela*, v. 1, no. 5, pp. 783–788, May 1959 (Translated from the Russian in *Soviet Physics—Solid State*, v. 1, pp. 711–715, 1959)**

Investigations were made on paraffin, naphthalene, sulfur, plexiglas, and ebonite for the purpose of clarifying the effect of an alternating electric field on the nature of the long-lasting polarization. It is shown that treatment of the dielectric first in an alternating, and then in a constant field, in a series of cases leads to an increase in the stability of the polarized state, and sometimes to a change in the direction of polarization.

121. THE ROLE OF FIELD IN FORMATION OF HETEROCHARGE OF A PHOTOELECTRET

Golovin, B. M., Kashukeev, N. T., Fridkin, V. M.
***Doklady Akademii Nauk SSSR*, v. 128, no. 1, pp. 63–66, September 1, 1959 (in Russian)**

An expression is derived for the stationary distribution of heterocharge along the length of the crystal in the direction of the applied field. It follows from the equation that the charge on the surface of photoelectret facing the anode is directly proportional to the intensity of the polarizing field, and the charge on the opposite surface is independent of the field intensity. (*PA*, 1960, #2924)

122. PERMANENT POLARIZATION OF EBONITE

Polovikov, F. I.
***Fizika Tverdogo Tela*, v. 1, no. 11, pp. 1720–1726, November 1959 (Translated from the Russian in *Soviet Physics—Solid State*, v. 1, pp. 1572–1576, 1959)**

The charge in ebonite polarized at a given initial temperature depends on the polarizing field intensity but is independent of the duration of polarization. At a given polarizing field intensity the magnitude and sign of the polarization charge are governed by thermal conditions during polarization. At initial polarization temperatures below 70°C heterocharge predominates in ebonite, while at higher temperatures homocharge is mainly induced. High-frequency heating of ebonite shortens the duration of polarization and produces larger charges. (*PA*, 1960, #10022)

direction of the field was obtained. When the dielectric constant was measured at right angles to the direction of the field, the values of the treated material were found to be lower than those for the control sample. Alternating-current conductivity of the material was calculated from the measured values of ϵ and tan δ. (*PA*, 1960, #6159)

112. THE QUESTION OF THE ELECTRET STATE IN NAPHTHALENE

Beliaev, L. M., Belikova, G. S., Fridkin, V. M., Zheludev, I. S.

***Kristallografiya*, v. 3, no. 6, p. 762, November–December 1958 (Translated from the Russian in *Soviet Physics—Crystallography*, v. 3, no. 6, pp. 772–773, January 1960)**

Thermoelectrets were formed from melted naphthalene, and photoelectrets and thermoelectrets from single crystals of naphthalene. In all cases it was possible to depolarize completely the electrets by illuminating them with a mercury vapor lamp. The results indicate that there is no sharp demarcation between photoelectret and thermoelectret states, and that in both, the heterocharge is probably due to localized electrons. (*PA*, 1960, #13660)

113. DIELECTRIC RELAXATION POLARIZATION AND THE INNER FIELD IN CRYSTALS AND POLYCRYSTALS

Skanawi, G. I.

In "Semiconductors and Phosphors," Schön, M., Welker, H., Editors Interscience Publishers, New York, N. Y., 1958 (pp. 656–678)

It is argued that where the crystal structure of a dielectric is not known in sufficient detail to enable the inner field coefficients to be calculated, valuable information on the nature of the polarizable units may still be obtained from dielectric measurements. The outline of a theory is given which assumes an arbitrary inner field (Lorentz) factor and arrives at a set of Debye equations. Experimental results which have been interpreted in terms of this theory include measurements on hydrogenated castor oil (a wax), pure alkali halide crystals and ceramics in the strontium titanate–bismuth titanate series which show high permittivities without being ferroelectric. Recently discovered electret-like behavior in titanate dielectrics is also mentioned. (*PA*, 1960, #625)

114. ELECTRETS OF CERAMIC DIELECTRICS

Turek, M.

***Slaboproudy Obzor*, v. 20, no. 1, pp. 23–30, 1959 (in Czechoslovakian)**

The phenomenon of permanent polarization of certain dielectrics is briefly discussed and the Adams–Swann (1927 and 1950–1953) theory of electrets is outlined. It is pointed out that the theory is inadequate in the case of inorganic dielectrics and here the theory of A. N. Gubkin is of importance. The Gubkin theory is described in some detail and the parameters of a number of organic and inorganic electrets are tabulated. The technology of the preparation of various titanate ceramic electrets and steatite electrets is outlined. Laboratory and engineering applications (electrostatic voltmeters, condenser microphones, valves, picture tubes, memory elements, high-voltage generators, electrostatic induction generators and motors, photography) of ceramic electrets are briefly discussed. (*EEA*, 1959, #2830)

115. STATICAL CHARGES OF DEFORMED POLYMER

Bazan, C.

***Acta Physica Polonica*, v. 18, no. 2, pp. 87–92, 1959**

Thin plates of a polyvinylchloride clamped on two sides, heated above the softening point and then cooled to room temperature, acquire electrical charges. These charges have opposite sign on opposite sides of the sample. Plates prepared in this way show optical double refraction. From the observed patterns one concludes that the chain segments are oriented preferentially in the radial direction. This effect may be related to the electrification of the sample. It is suggested that the asymmetry of the electrical charges may be due to polar group orientation. (*PA*, 1960, #16008)

116. ELEKTRETY: ELEKTRICHESKIYE BLIZNETSY MAGNITOV (ELECTRETS: ELECTRIC ANALOGS OF THE MAGNETS)

Zayev, N.

***Tekhnika Molodezhi*, USSR, v. 27, no. 3, pp. 37–39, 1959 (Translation Summary 59-19694, September 17, 1959, obtainable from the Library of Congress or Special Libraries Association)**

After a theoretical explanation of the electret structure, its analogy to a permanent magnet, and ability to accumulate electric energy, the author gives some information

123. THE DEPOLARIZATION CHARGE OF BARIUM TITANATE AND ITS CONNECTION WITH THE PIEZOELECTRIC EFFECT

Kolomoitsev, F. J., Izhak, I. A.
***Fizika Tverdogo Tela*, v. 1, no. 12, pp. 1791–1793, December 1959 (in Russian)**

Briefly describes an experiment in which disk-shaped specimens of $BaTiO_3$ were set up for piezoelectric measurements. The specimens could also be heated through the Curie point and the depolarization charge measured. The results show that the depolarization charge is proportional to the piezoelectric modulus and the constant was determined experimentally. The result is in excellent agreement with theoretical calculations. (*PA*, 1960, #10019)

124. THE PHOTOELECTRET STATE AND THE LUMINESCENT AFTERGLOW IN ZnS

Fridkin, V. M.
***Doklady Akademii Nauk SSSR*, v. 129, no. 4, pp. 773–776, December 1, 1959 (in Russian)**

Polycrystalline ZnS was activated with Cu and Cl, and polystyrene was used as binder. The light sum stored in the specimen when excited with light in the absence of a field, and the photoelectret charge arising in the same specimen in identical conditions, but with a field, were measured simultaneously. The latter was measured by the method of Nadzhakov and Kashukeev (1951, 1952); the light sum was measured with a photomultiplier and an oscillograph. It was found that the photopolarization vs. logarithm-of-exposure curve (for $E = 400 \times 10^{-6}$ w/cm^2) shows saturation at $Et = 10^{-3}$ w sec/cm^2, whereas, for the same E, the light-sum vs. logarithm-of-exposure curve shows saturation at 10^{-4} w sec/cm^2. Moreover, while the processes of formation of the photoelectret state in ZnS are associated with the fulfillment of the law of interchangeability, deviations from this law are observed for the light sum. The afterglow in ZnS lasts only a few seconds, whereas the photoelectret charge in ZnS keeps on decreasing for a few tens of hours. An attempt is made to explain the mechanisms of the two phenomena. (*PA*, 1960, #10023)

125. NEW ELECTROPHOTOGRAPHIC PROCESS ACCOMPLISHED BY MEANS OF COMBINED ELECTRET LAYERS

Golovin, B. M., Zheludev, I. S., et al.
1960
***Doklady Akademii Nauk SSSR*, v. 129, no. 5, pp. 1008–1011, 1959 (Translation 60-14660, obtainable from the Library of Congress or Special Libraries Association)**

Experiments were made with combined electret layers in which cadmium sulfide activated by copper and chlorine was used as the photoconducting layer. The electret layer was electroluminescent zinc sulfide, also activated by copper and chlorine. As the binding agent for CdS we used polystyrol or epoxide resin. The thickness of the CdS layer was approximately 150 μ. The dark resistance was 10^4 Ω. The thickness of the electret layer was approximately 50 μ. The relation between the charge of the ZnS electret and the tension of the polarizing field (dark polarization) was linear. The reciprocity law failure for the combined electret layers was not fulfilled. The minimum energy, for which the difference for the initial depolarization currents is different from zero ($i_0 > 0$), was in one case 10^{-6} w/cm^2 sec and in the other case, 4×10^{-7} w/cm^2 sec. (*TT*, 1960, T-3152)

126. SOME EFFECTS OF VAPORS ON ELECTRET BEHAVIOR

Beeler, J. R., Jr., Stranathan, J. D., Wiseman, G. G.
***Journal of Chemical Physics*, v. 32, pp. 442–446, 1960**

The effects of various vapors on the growth and decay of electret polarization have been studied. Particular emphasis was given to the effect of water vapor on polyvinyl acetate. The observed effects appear to arise from two causes: (1) a decrease in the relaxation time and an increase in the magnitude of the volume polarization following infusion of vapor into the dielectric; (2) an increase in the transfer of charge by means of interfacial discharge at the dielectric-electrode gap. The infusion of a polar vapor into a nonpolar solid dielectric gave anomalously large values of volume polarization. The dielectrics studied were polyvinyl acetate, polyethylene, two acrylic resins, and carnauba wax. The vapors used successfully were water and chlorobenzene; unsuccessful attempts were made to use benzene and isopropyl ether.

127. DECAY OF WAX ELECTRETS

Perlman, M. M.
***Journal of Applied Physics*, v. 31, no. 2, pp. 356–357, February 1960**

The internal field within an electret can be varied by changing the spacing and arrangement of shielding electrodes ("partial shielding"). The application of this technique to rosin-wax electrets shows that the charge decay observed upon unshielding electrets is caused primarily by volume polarization due to internal field rather than by external ion collection. (*PA*, 1960, #5261)

128. THE PIEZO EFFECT IN ELECTRETS

Gubkin, A. N., Sorokin, V. S.
***Izvestia Akademii Nauk SSSR, Seriya Fizicheskaya*, v. 24, no. 2, pp. 246–252, 1960 (in Russian)**

1958 Moscow Dielectrics Conference. The theory of the piezo effect in electrets is developed, with special reference to the influence of the gap between the electrodes and the specimen. It is concluded that there is a genuine effect, obtained with zero gap, and a "quasi" effect, obtained with a finite gap. Experiments with a number of titanate ceramics show that only barium titanate and a mixed strontium–bismuth titanate exhibit the genuine effect. The nature of the "quasi" effect is studied experimentally on the other ceramics. (*PA*, 1960, #18105)

129. PHOTO-ELECTRET STATE IN ZINC SULPHIDE AND TWO NEW ELECTRO-PHOTOGRAPHIC PROCESSES

Golovin, B. M., Kashukeev, N. T., Orlov, I. N., Fridkin, V. M.
***Fizika Tverdogo Tela*, v. 2, no 5, pp. 1004–1010, May 1960 (in Russian)**

The photoelectret characteristics of polycrystalline ZnS, activated with Cu and Cl and exhibiting electroluminescent properties, were studied. The effect of the intensity of the polarizing field and the energy of illumination on the charge of ZnS photoelectrets was determined, and curves, illustrating the polarization (dark, photo, and total) phenomena, were constructed. One of the particularly interesting properties of ZnS photoelectrets was their capability of being depolarized by the application of an alternating electrical field, the depolarization process being accompanied by electroluminescence of the photoelectret. It was postulated that these effects may have some bearing on the formation of images on electrophotographic ZnS and ZnO films, depolarized in an alternating electrical field. (*PA*, 1960, #13661)

130. CONTACT ELECTRIFICATION AND POLARIZATION OF NYLON THREADS

Arridge, R. G. C.
***British Journal of Applied Physics*, v. 11, no. 5, pp. 202–205, May 1960**

A study has been made at different relative humidities of the way in which electric charges on nylon threads decay. For relative humidities of less than about 35 percent, the charges remain localized and decay in magnitude at very nearly an exponential rate. For relative humidities greater than 35 percent the charges spread out along the thread and the decay of peak charge with time can be approximately represented by a $t^{-\frac{1}{2}}$ law rather than by an exponential one. If a diffusion equation of the type $\rho = At^{-\frac{1}{2}} \exp(-\chi^2/4Dt)$ is applied to the latter results, values of the diffusion constant D are obtained which are independent, within the accuracy of the experiment, of (1) the sign of charge and (2) whether it was a contact charge or a polarization charge. D varies exponentially with relative humidity. (*PA*, 1960, #7056)

131. ON THE THEORY OF FORMATION OF LATENT ELECTROPHOTOGRAPHIC IMAGES ON PHOTOELECTRETS

Fridkin, V. M.
***Journal of the Optical Society of America*, v. 50, no. 6, pp. 545–550, June 1960**

The process of formation of persistent internal photopolarization in crystals is considered on the basis of the band theory. The results obtained may be used in analyzing the process of formation of latent electrophotographic images. (*PA*, 1960, #10021)

132. THE AMATEUR SCIENTIST—HOW TO MAKE AN ELECTRET: THE DEVICE THAT PERMANENTLY MAINTAINS AN ELECTRIC CHARGE

Stong, C. L.
***Scientific American*, v. 203, no. 5, pp. 202–210, November 1960**

133. HIGH-TEMPERATURE DISCHARGES IN FERROELECTRIC CERAMICS

Northrip, J. W.
***Journal of Applied Physics*, v. 31, no. 12, pp. 2293–2296, December 1960**

Ceramic disks of barium titanate and lead zirconate

titanate, when heated above 100°C, exhibit current discharges which cannot be attributed to the ferroelectric polarization of the material. These discharges are largest in the temperature interval 300–600°C and depend primarily on the electrode material and its method of application. Discharges of several millicoulombs at voltages up to one-half volt have been obtained from a ceramic disk one-half inch in diameter and 30 mils thick having a silver electrode and an indium counterelectrode. Although thermoelectric, pyroelectric, and electret effects are observed in these samples, these phenomena contribute only a very small portion of the total discharge. At constant temperature near 350°C the discharge decays with time as the sum of two exponentials, falling to half maximum in periods of the order of one-half hour. At higher temperatures the decay rate increases, while temperature cycling produces a voltage cycling superimposed on the decay. These findings support an explanation of the effect in terms of solid-state chemical activity between the metallic electrodes and the titanate lattice.

ASSOCIATED SUBJECTS

134. THERMAL CONDUCTION IN ELECTROSTATIC FIELDS
Groetzinger, G., Frey, R.
Physikalische Zeitschrift vereinigt mit dem Jahrbuch der Radioaktivität und Electronik, v. 36, pp. 292–298, April 15, 1935

In this paper it is shown experimentally that the thermal conductivity of certain liquids is altered by an electrostatic field. With solids and gases free from a permanent electric moment, no such influence of an electrostatic field could be established. Senftleben, whose results are challenged by the authors, claims to be in agreement with those in the present paper, since the experimental arrangements were different, and these are not discussed. (*PA*, 1935, #2619)

135. THE PRESENT STATE OF THE PHYSICS OF DIELECTRICS
Vul, B. M.
Elektrichestvo, no. 1, pp. 3–12, January 1949 (in Russian)

A review with a bibliography of 46 references, 45 of them being Russian. (*PA*, 1949, #6292)

136. THEORY OF ORIENTATION POLARIZATION
Borgardt, A. A., Finkelshtein, B. N.
Doklady Akademii Nauk SSSR, v. 67, no. 6, pp. 981–984, 1949 (in Russian)

137. ON THE THEORY OF POLARIZATION OF DIELECTRICS
Shakhparonov, M. I.
Doklady Akademii Nauk SSSR, v. 111, no. 4, pp. 815–817, 1957 (in Russian)

138. THE EFFECT OF A SURFACE CHARGE LAYER ON POLARIZATION OF POLYCRYSTALLINE BARIUM TITANATE
Lure, M. S., Ignateva, I. V.
Fizika Tverdogo Tela, Sbornik [Supplement] I, pp. 190–195, 1959 (in Russian)

A study of pyrocurrents (currents produced by change of polarization on rise of temperature) in ceramic and monocrystalline barium titanate showed that surface space-charge layers are responsible for the observed domain configuration. (*PA*, 1960, #16013)

139. ON SURFACE LAYERS OF $BaTiO_3$
Brezina, B., Janovec, V.
Czechoslovakian Journal of Physics, v. 9, no. 6, p. 758, 1959

Above the Curie point, *a*-domain crystals remain birefringent near one of the two surfaces perpendicular to the polarization direction. A possible explanation of the mechanical stress near the surface layer is given. (*PA*, 1960, #11744)

140. AN INVESTIGATION OF ELECTRIC FIELDS IN ANALOG DIELECTRICS
Douglas, F. C.
October 19, 1959
Electronic Defense Lab., Mountain View, Calif.
TM EDL-M155, DA 36-039-sc-78281
AD-229,201

An artificial dielectric was used as the analog of a crystal model subjected to an electric field. The polarizability of the simulated dipoles was measured and compared with a theoretical value. The relative permittivity of a cubic crystal analog was obtained as a function of the number of planes of dipoles it contained; the relative permittivity of a tetragonal crystal analog was obtained as a function of the axis of symmetry lattice constant. An attempt was made to verify a theoretical polarization expression for the local field at a lattice point in a tetragonal crytal. (ASTIA)

141. X-RAY INDUCED ELECTRICAL POLARIZATION IN GLASS
Proctor, T. M.
Physical Review, The, v. 116, no. 6, pp. 1436–1440, December 15, 1959

Electrical polarization was induced in a lead silicate glass by the action of X-rays. This phenomenon is surveyed experimentally as a function of total dose (incident and absorbed), dose rate, X-ray tube potential, radiation temperature, and temperature at which the polarization

is released and measured. Net surface charges of the order of 10^{-9} coulomb/cm^2 can be obtained from 3 mm thick sample irradiated at room temperature with 10^5 roentgen of 250 kv X-rays. To the first order, the build-up and decay of this condition seems to follow the normal electrical relaxation as can be theoretically predicted from the dielectric and resistivity constants of the material ($\tau = \rho\varepsilon$). Measured surface charge is shown to be proportional to absorbed dose for smaller doses; however, for greater doses final equilibrium in the polarization is reached when back electrical conduction becomes as large as the forward X-ray induced displacement current. The dependence of measured surface charge upon the sample thickness was experimentally investigated for one case. (*PA*, 1960, #2926)

142. THE EFFECT OF PRESSURE ON PIEZOELECTRIC PROPERTIES OF BARIUM TITANATE

Rotenberg, B. A.
***Fizika Tverdogo Tela*, v. 1, no. 12, pp. 1777–1781, December 1959 (in Russian)**

The piezoelectric polarization, P, induced in barium titanate was studied using hydrostatic (three-directional) and unidirectional pressure on monocrystals, and using hydrostatic, two-directional and unidirectional pressure on polycrystals ($BaTiO_3$ ceramics). On hydrostatic compression the piezoelectric polarization varied linearly with pressure up to 1000 kg/cm^2. The anomalous behavior of the piezoelectric polarization on unidirectional and two-directional compression (maxima and a change of sign of P at high pressures) was due to domain reorientation by mechanical stresses. (*PA*, 1960, #11748)

143. CONTRIBUTIONS TO THE SECOND ALL-UNION CONFERENCE ON THE PHYSICS OF DIELECTRICS

***Izvestiya Akademii Nauk SSSR, Seriya Fizicheskaya*, v. 24, no. 1, pp. 1–112; no. 2, pp. 114–256, 1960 (in Russian)**

The conference was held November 20–27, 1958, in Moscow. Thirty-four papers were presented, abstracts of which will be published (under the appropriate headings) in this or succeeding issues of *Physics Abstracts*. (*PA*, 1960, #16003)

144. THE KINETICS OF IONIC CONDUCTIVITY AND ELECTRICAL POLARIZATION IN SOLIDS

Khait, Yu. L.
***Izvestiya Akademii Nauk SSSR, Seriya Fizicheskaya*, v. 24, no. 2, pp. 202–211 (Discussion, pp. 212–214), 1960 (in Russian)**

1958 Moscow Dielectrics Conference. Uses methods of statistical physics, with a mean free path, for calculating the speed of activated processes in solids in external fields. Processes occurring in a dielectric in an electric field can be connected with the heat conductivity and other nonelectrical quantities. The mean free path must be derived from experiment. (*PA*, 1960, #18086)

145. THE EFFECTIVE FIELDS IN CRYSTALS

Bogomolov, Yu. V.
***Fizika Tverdogo Tela*, v. 2, no. 2, pp. 297–301, February 1960 (in Russian)**

A generalization of the Lorenz–Lorentz formula is given for the case of a crystal and includes terms up to the order of α^3 (α is the polarizability). To this approximation, the "crystal" polarizabilities of the naphthalene molecule have been calculated as $(\alpha_1,\alpha_2,\alpha_3) = (10.2,15.4,26.3) \times 10^{-24}$cm^3. The usual Lorenz–Lorentz formula gives (12.3, 18.6,21.4), as compared with Sundrarajan's values of (10, 19,27). (*PA*, 1960, #11736)

146. METHODS OF MEASURING A HIGH-VOLTAGE POLARIZATION POTENTIAL

Prokopalo, O. I.
***Fizika Tverdogo Tela*, v. 2, no. 2, pp. 302–305, February 1960 (in Russian)**

The equivalent circuit of a polarized dielectric is complicated in the general case but can be used: (1) when a thin layer is formed at the electrode, and (2) when the potential distribution is linear. The equivalent circuits in these two cases throw light on the limits within which each of the various methods proposed for measuring polarization in dielectrics can be applied. An expression is found for the recorded electrometer potential as a function of time in the case of a linear distribution and verified by an experimental curve for $BaTiO_3$. (*PA*, 1960, #13659)

147. PYROELECTRICITY, INTERNAL DOMAINS, AND INTERFACE CHARGES IN TRIGLYCINE SULFATE

Chynoweth, A. G.
***Physical Review, The*, v. 117, no. 5, pp. 1235–1243, March 1, 1960**

Using the dynamic pyroelectric technique, the spontaneous polarization of triglycine sulphate was determined between the Curie point and −140°C. No evidence of any phase transitions over this temperature range was found (other than the Curie point). The polarization could still be reversed by an applied field, though slowly, at the lowest temperatures attained. In the paraelectric region above the Curie point, the pyroelectric behavior shows some deviations at low applied fields from the predictions of Devonshire's theory. The cause of these deviations is not known but they may be due to uniform conditions, either mechanical or electrical, in the crystal. With no field applied to the crystal, pyroelectrical signals can be generated temporarily above the Curie point. These are ascribed mainly to polarizations induced by the compensation charges, while they last, which accumulate around residual domains that cannot be removed by the poling field at room temperature. These residual domains have been delineated using powder pattern and etching techniques and are revealed as long thin domains, pointed at both ends and lying along the ferroelectric direction, either in the interior of the crystal or intercepting the surfaces. The causes of these persistent domains are not known. It is found that on cooling a crystal through the Curie point, there is a strong tendency for it to repolarize with the same polarity it had previously. This phenomenon is ascribed to the presence of ferroelectrically inactive surface layers giving rise to interface charges. *(PA*, 1960, #6160)

148. SPACE CHARGE FIELDS IN $BaTiO_3$

Triebwasser, S.
***Physical Review, The*, v. 118, no. 1, pp. 100–105, April 1, 1960**

Observations were made in the presence of dc electric field bias of: (1) hysteresis loops; (2) double loops above the Curie point; (3) Kerr electro-optic effect above the Curie point; and (4) capacitance above the Curie point in $BaTiO_3$. The purpose of these experiments was to determine field distributions in the crystal under an externally applied difference of potential and to examine the extent to which space-charge surface layers cancel the bulk field. The first three types of observations were qualitative in nature. The biased hysteresis loops show normal behavior with no evidence of field cancellation. Double loop measurements show some evidence of field cancellation, while Kerr electro-optic measurements show strongly nonuniform fields indicating anomalous space-charge fields. The measurements of capacitance above the Curie point indicate that surface layers build up in the presence of a dc field, and these surface layers have a capacitance that varies with applied voltage. The results can be understood qualitatively if simple Schottky exhaustion barriers are assumed at the two metal electrode–crystal contacts. Observed asymmetries with respect to the applied fields are discussed. *(PA*, 1960, #10020)

149. INFLUENCE OF CRYSTALLOGRAPHIC ORIENTATION ON THE CHARGE FORMATION DURING PHASE CHANGES IN SOLIDS

Mascarenhas, S., Freitas, L. G.
***Journal of Applied Physics*, v. 31, no. 9, pp. 1684–1685, September 1960**

The effect of charge separation during phase changes (Costa Ribeiro effect) is studied with naphthalene single crystals. By properly seeding the melt it was shown that the effect is dependent on crystallographic orientation. Values of the trapped charge are 32×10^{-9} coulomb/g for growth normal to cleavage plane, 2.5×10^{-9} coulomb/g for growth along *b* axis, and 2.9×10^{-9} coulomb/g for growth along the solid phase this observation may be important in zone refining techniques. If it is due to an electronic effect this points-out to an orientation-dependent double layer at the solid–liquid interface. *(PA*, 1960, #16005)

150. THE ELECTRICAL PROPERTIES OF SOME NATURAL WAXES

Callinan, T. D., Parks, A. M.
***Electrochemical Society, Journal of the*, v. 107, no. 10, pp. 799–803, October 1960**

The dielectric constants and dielectric loss factors of carnauba, ouricuri, and American montan wax, determined over a temperature range from −60 to 90°C and at frequencies of 0.1, 1, 10, and 100 kc, indicate that the component omega-hydroxy acid esters rotate in the solid state in the temperature region 25–70°C. From dipole measurements, the molecules were found to possess a trans-trans configuration. *(PA*, 1960, #18089)

AUTHOR INDEX*